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MANUAL OF GEOLOGY

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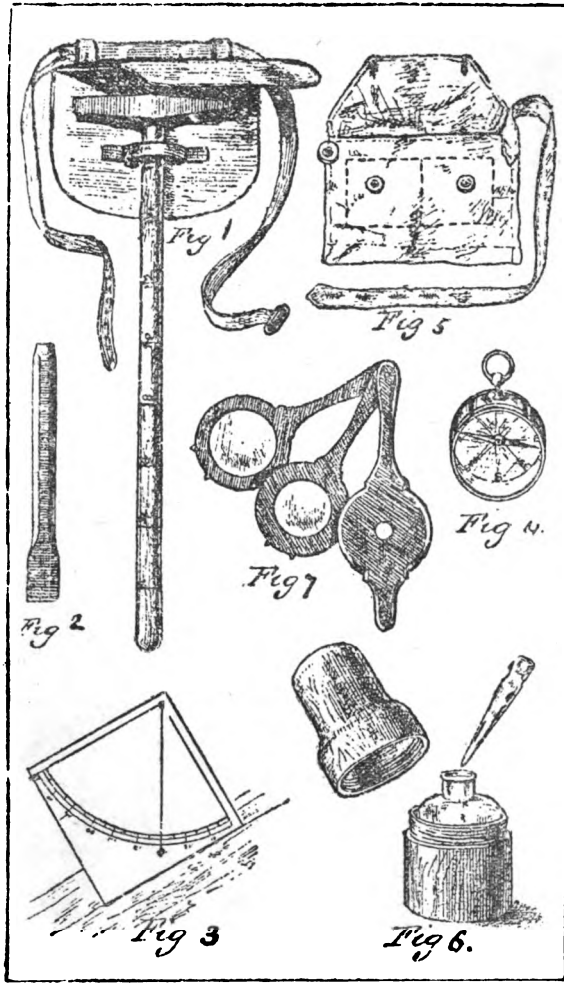

GEOLOGICAL APPARATUS (see chap. ii.).

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Stewart's Educational Series.

PRACTICAL GEOLOGY.

BY

W. JEROME HARRISON, F.G.S.,

EDITOR OF THE 'MIDLAND NATURALIST;'
CURATOR OF THE TOWN MUSEUM, LEICESTER; AUTHOR OF THE 'GEOLOGY OF LEICESTERSHIRE AND RUTLAND,' ETC. ETC.; FIRST IN FIRST-CLASS HONOURS IN GEOLOGY AND IN PHYSICAL GEOGRAPHY, SCIENCE AND ART DEPARTMENT.

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PREFACE.

In this little book I have tried to show the reader how to see for himself the leading facts of Geology. In all scientific studies, theoretical and practical work must go together hand in hand, but our ordinary geological text-books do not set forth sufficiently the need for actual work in the field, nor do they give instructions how to set about it. The success of my geological classes in connection with the Science and Art Department has been mainly due to a constant insistance on the necessity for field work, combined with the close examination, sketching, etc. of models and specimens. The great thing is to get into the open air, and to hammer away at every rock in the neighbourhood, even though one should be

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mistaken, as Sedgwick once was, for a parish stone-breaker!

Every fact that is personally observed will give a desire and zest to the search for its explanation, and will send the student with renewed energy to his text-books.

I have also tried to break as much new ground as possible, both in the matter and in the manner of putting it. Some of the illustrations are original, and the others have been selected from scarce and expensive works of reference.

W. J. H.

LEICESTER, *October* 1878.

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PRACTICAL GEOLOGY.

CHAPTER I.

PREPARATION.

PERHAPS there is no subject in which it is more difficult to obtain practical instruction of real value than the science of Geology. The professorships connected with its teaching might be counted on the fingers of one hand, and there are probably not half-a-dozen 'coaches' in the United Kingdom who pay their chief attention to this subject.

If we go to the 'practical man,' who above all others might be supposed to be able to give us information,—as the colliery manager, the master well-sinker, or the overseer of mines,—it is but too probable that we shall find these gentlemen possessed of but the shallowest and most superficial knowledge.

Fortunately the remedy is, to a large extent, in the hands of every student, and it is *to teach himself by observation.*

'How simple!' the reader exclaims; but, unfortunately, it is not so. The acquirement of a pair of geological eyes is necessary, and this will neces-

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sitate much thought, much reading, and much walking.

At the very commencement, the first thing to be done is to read carefully some good text-book. There are several well fitted for this purpose; but if we begin with Geikie's little '*Science Primers' of Physical Geography and Geology*, and then Jukes' *School Manual of Geology*, we shall find ourselves fitted to encounter some more advanced book, as Lyell's *Student's Elements*, with the power of understanding and grasping it. It is a great thing to get up these books *thoroughly*, to fix them in the mind paragraph by paragraph, so that they form standards of reference to which we can submit any statement we may come across. But it is this portion—the theoretical—which will probably be already in the minds of those who may read these pages. It is at this point that too many stop. They cram up sufficient by reading to pass some given examination, and then rest contented, without ever having tasted the pleasure which might accrue to them from the application of the knowledge they possess, which soon fades from their mind like an unfixed photograph.

Certainly, no land area in the world has been so well examined, geologically speaking, as the British Islands; and yet one consequence of this is, that in no country can the beginner set to work with a greater certainty of increasing not only his own stock of knowledge, but of aiding the cause of geological science in general.

But will the knowledge thus obtained *pay* in examinations? Most certainly it will. In no subject does practical knowledge meet with more ready recognition, for the examiners are themselves men to whom the rocks of this island are as familiar

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as are to us the shops in the street along which we pace our daily way. They have mostly been trained in the finest geological school in existence —the Geological Survey of Great Britain, of whose officers it might be said, as it was of Buckland, that, if they were blindfolded and set down on any road in the kingdom, they would but require to pick up the neighbouring stones to tell the spot on which they stood.

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CHAPTER II.

APPARATUS.

STARTING, then, with a fair knowledge of theory, we must first obtain a good *map* of the neighbourhood in which we live. The Ordnance maps, on the scale of one inch to a mile, are those best suited to our purpose. If we obtain from the nearest bookseller a *Catalogue of the Publications of the Geological Survey*, we shall find such particulars as will enable us to order the sheet, or quarter-sheet, containing our district; and this will have the immense advantage of being *coloured*, so as to show where the different beds of rock occupy the surface. If we live on the eastern coast, we shall not be able to obtain these coloured maps, as East Yorkshire, Lincoln, Norfolk, and Suffolk are now in process of examination by the working parties of the Survey, and coloured maps of them have not yet been issued. Of some districts, chiefly the coal-fields, we can obtain larger maps, on the scale of six inches to a mile; and probably all England will be geologically mapped on this scale when the present one-inch maps are finished. The latter are, however, perhaps the best for beginners. Of general geological maps, Ramsay's England and Geikie's Scotland are excellent. One thing, however, the student must be cautioned against.

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When he looks at his gaily-coloured map, he must not suppose that the veritable rock whose name he sees appended to the colour is of necessity actually to be found there at the surface. To begin with, all rocks decompose and form *soils*, which, however, the experienced eye can refer to their parent rock. But we meet with a greater obstruction in the form of what is commonly termed *drift*, the irregular beds of clay, sand, or gravel which in certain districts entirely mask or conceal the subjacent beds and prevent their examination. This drift has not hitherto been marked on the Government maps of which we have been speaking; but a fresh examination of the whole country is now being made, and a separate set of maps will be issued in the future, on which this drift will be distinguished and coloured. Such a map has already been issued for London and the neighbourhood. These maps will be even more valuable to the agriculturist, and all who are concerned with surface workings, than those of the ordinary series.

In giving the following notes upon some other apparatus, which the geological student will find of use in his work, it need scarcely be said that they are not indispensable. We have known admirable work done with rough, self-devised tools, while the energies of others appear to have been exhausted in the act of procuring an elaborate set of instruments, which only serve to ornament the walls of their studies.

Hammer.—How dear is this instrument to the beginner among rocks! Never go out geologizing with a man who is not provided with one; he will be certain to be constantly requisitioning that which you have brought for your own especial benefit. Any ordinary hammer will answer; but it is pre-

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ferable to order one with a *square* face, the head tapering to a horizontal chisel edge at the other end. The head should be about one inch square and five inches long, of well-tempered but not too hard steel. It is best carried in a leather belt round the waist, the handle passing through a slit, while an oval piece of leather passes over the head and prevents it from soiling the clothes (see fig. 1).

To use this hammer with the best effect, it should be held lightly, yet firmly, by the lower end of the handle; and the strokes should be made smartly and from the elbow, being directed so as to bring an edge of the face along any natural lines of cleavage or lamination which may be seen in the rock operated upon. A small *trimming hammer*, with a face half an inch square, is very useful in reducing specimens to a fit size for the cabinet.

Chisels (see fig. 2).—In extracting fossils from rocks, or in clearing them from the stony matrix, we shall find one or two iron chisels of great service.

Clinometer (see fig. 3).—In examining beds of rock in quarries, cuttings, etc., we frequently see them *dip* or incline in a greater or less degree. For many purposes it is very important to know the amount of deviation from horizontality, or the *angle of dip*. The clinometer is used for this purpose, and is of various forms. A very simple one may be made out of a thin piece of wood or stout cardboard, say four or five inches square. From one corner of the square describe a circle passing through the adjoining corners, and divide the arc so obtained into ninety degrees, marking, say, every five degrees. Bore a fine hole near the corner, and suspend from it a small bullet by a piece of silk thread.

If the edge of the square be now placed on the

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sloping bed, or if, better still, we stand back a little way and make the edge agree with the general dip, we shall be able to mark the place where the silk thread crosses the arc, which will give the amount of dip. Of course, if the beds dip 45°, the thread will mark the diagonal of the square. This is very simple, but a piece of apparatus made by a student with his own hands, and used by him in practical researches, is likely to teach him more than an expensive purchased article.

Compass.—A small compass, even one that can be carried on the watch-chain (see fig. 4), is very useful in ascertaining one's position, and in enabling one to distinguish between distant hill-tops, church spires, etc., when combined with a reference to the map. A *prismatic compass* is one which enables us to read off the angle made by any object with the magnetic meridian. Further, when we can thus ascertain the angles of any two objects, it enables us to lay down our exact position on the map, which is often no small advantage on a long stretch of road or a heathy moorland. A compass is also of use in detecting the presence of iron ore.

Wallet or Bag (see fig. 5).—This is best made of stout grey jean, doubled and double sewn all round, with a strap to pass round the shoulders. It can then be carried beneath the coat when 'outward bound,' so that it need not be visible. It should contain two interior pockets for special objects, and all specimens should be folded in paper before being put in. A piece of paper should also be wrapped up with each, giving the exact locality; or a number may be gummed on, referring to an entry in the note-book. Chip boxes and a little cotton wool should be taken, if we are likely to meet with fragile fossils or delicate crystals.

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A stout little *acid bottle*, containing hydrochloric acid diluted with an equal bulk of water, is very serviceable in deciding whether any rock contains carbonate of lime, as we perceive a more or less brisk effervescence when the dilute acid is brought into contact with this mineral. Very convenient little bottles can be purchased, having wooden cases and stoppers reaching down into the liquid, by which a drop can be readily taken out and placed upon the rock (see fig. 6).

A pocket magnifying glass (see fig. 7) enables us to decide in many cases whether a rock is aqueous or igneous, when we could not tell by the naked eye. The crystalline structure of the latter class will mark it out from the rounded character of the component grains of the former. A surface that has been long exposed to the action of the weather will often give more valuable evidence than a fresh fracture.

A strong *tape measure* is needed for measuring purposes; and it is also useful to have the handle of your hammer marked every two inches. A *note-book* and *pencil* must, of course, not be forgotten.

Thus equipped, we will go forth into the field resolved to master the structure of the little corner of the earth in which we dwell. We must endeavour to trace out both the history of the rock masses which compose it, and also the causes which have led to its surface configuration, so familiar to our eyes, but whose *raison-d'être* is, as a rule, so little thought of or understood. Collecting rocks and fossils, we must endeavour to *determine* them—that is, to find out their names. In this way we shall improve our bodily health and gain a truly practical knowledge of our subject, the only kind of knowledge which is really worth having.

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CHAPTER III.

IN THE FIELD.

PROVIDED, then, with such of the articles of apparatus already described as he can obtain, the student may now begin the actual work of examination of that portion of the earth's crust which is exposed in his immediate neighbourhood.

In indicating the method of procedure, much will now depend on the part of the country in which the observer may dwell, whether among granitic and metamorphic rocks, or near coal-fields, or on the later-formed comparatively incoherent tertiary deposits, and we shall arrange our notes accordingly.

To begin with, it is very desirable to work in company with others. In any case, the presence of a companion to whom to communicate our thoughts and discoveries is advantageous; but if a field-club or society, having for its aim the scientific exploration of the district, be within reach, it will be a great privilege to enrol ourselves in its ranks. In London the *Geologists' Association* is an excellent society of this kind, having its headquarters at University College, and holding weekly excursions or visits to museums, and also monthly evening meetings, at which papers are read and

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discussed. If the neighbourhood in which we live is very uninteresting, geologically speaking, much may be done by excursions, and by arranging to pass our holidays in the region we wish to study.

AMONG THE OLDER PALÆOZOIC ROCKS.—Whether resident or visitor, let us imagine the reader to be within walking distance of those old rocks which form the base of the whole rocky structure of these islands. We will endeavour to point out to him *what to look for*, and what further, as his geological knowledge increases, he should *work for*, in the desire to increase the sum of geological knowledge.

Estimating the total thickness of stratified rocks at 20 miles, we find the base occupied by a series of beds, to which the name *Laurentian* has been applied, from their extensive development to the north of the river St. Lawrence in Canada. The best general account of these rocks is to be found in a work lately published by Principal Dawson, entitled *The Dawn of Life*. Now, in the western islands of the Hebrides, all the chain from the Butt of Lewis to Barra Head, together with Tiree, Coll, and Iona, which lie nearer to the mainland, we have a succession of low, rounded, hummocky hills, composed of a coarse-grained, pinkish-grey gneiss. Crossing the Minch, we can detect the same beds forming just the north-west corner of Sutherland, and also in Ross along the shores of Loch Maree. These beds have been correlated by Murchison with the Laurentian beds of Canada; but the student should be strongly cautioned against supposing them to have been in consequence formed at exactly the same time, and indeed it would perhaps have been better to have retained for the Scottish beds the name of *Lewisian* or *Fundamental*

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Gneiss, than to have conferred on them a name which will be apt to mislead.

If we bring into use our clinometer, we shall find these gneissic beds to have a high dip towards the S.W., although they are so contorted and crumpled that we shall have to take our stand at some distance from the rock to get the main inclination. As a consequence, the *strike* is from N.W. to S.E., *i.e.* at right angles to the dip; and this direction of the strike is very characteristic of Laurentian beds. For a further description of them, the student should read Sir R. Murchison's *Siluria*, which is indeed indispensable to every worker among Palæozoic beds. *Eozoon*, which is the characteristic Canadian fossil of the Laurentians, has not yet been found in Scotland. It should be sought for in bands of crystalline limestone. It was thought a short time ago that a specimen of this earliest simple foraminifer had been obtained from Harris (one of the Hebrides), but a further examination by Dr. Carpenter showed that the apparent structure was mineralogical only.

Is there any other 'uncovered area' of Laurentian rocks in Great Britain? Dr. Hicks, so well known from his researches in the Cambrian beds of Wales, has found in the promontory of St. David's a syenitic ridge which underlies the oldest Cambrian rocks, and the strike of which is from N.W. to S.E., being quite discordant to the overlying Cambrians. Dr. Holl has long endeavoured to spread his conviction that the syenites of the Malvern Hills should also be placed in this basal formation, but the point cannot be regarded as proved. The rocks of Charnwood Forest, in the very centre of England, have also been placed in the same category; but, from a long and minute

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personal investigation, we have been led to adopt very different views, and to place them rather with the Silurian system.

Gneiss.—As gneiss is the typical Laurentian rock, it may be well to devote a few words here to its description. It is composed of three minerals, quartz, felspar, and mica, not mixed up thoroughly together as in granite, but arranged in irregular leaves or layers. Hence it might be called a foliated or schistose granite.

Determination of Rocks.—It is very difficult to get a good idea of a rock from a written description of it. The best book on the subject is the translation from the German of Von Cotta's *Rocks Classified and Described.* But museums are now common. The dweller in London has the advantage of an unrivalled series in Jermyn Street Museum, whilst most county towns possess something of the kind. Then small collections of typical rocks may be had for a small sum from dealers in such objects, as Mr. Gregory of 88 Charlotte Street, Fitzroy Square. At first name every specimen you collect as well as you can, and then get some competent geologist to look them over for you. A polite request to this effect will rarely be refused, for there is no greater pleasure to a true geologist than to extend the knowledge of his favourite science so far as his time will permit.

Microscopical Examination.—Of late years quite a new method of examining rocks has sprung up. This consists in obtaining as thin a fragment of the rock as possible, and submitting it to careful scrutiny under varying powers of the compound microscope. Mr. Sorby, F.R.S., of Sheffield, was the inaugurator of the method in this country, and in his recent address to the Microscopical Society

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(of which he is the president) he has given a full and excellent account of the subject. If a thin

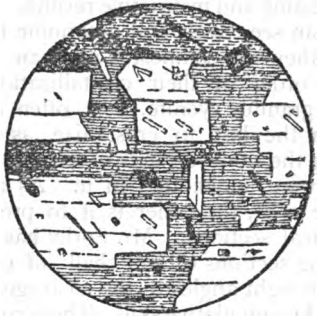

Fig. 8. Magnified section of Trachyte.

slice of the rock can be obtained with some lapidary's machine, such as that invented by Mr. Jordan of the Geological Survey, so much the better, but it will do if we chip off as thin a piece as possible with a hammer. This should now be cemented to a piece of plate glass, and rubbed down to a level surface on a piece of sheet lead with fine emery powder. Afterwards it must be polished, first on Water of Ayr stone (to be obtained at any marble-mason's), and then on marble with water. Now removing the cement by which it has been fastened to the glass, we must reverse and again affix it, and treat the other side in the same manner. In this way, with practice, it is possible to obtain sections from $\frac{1}{100}$ to $\frac{1}{1000}$ of an inch thick of any rock. Sections so thin are quite transparent, and under the microscope they can be examined by transmitted light. The whole structure of the specimen

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then becomes visible, and even the most homogeneous and glassy-looking rocks yield, especially when we call in the aid of the polariscope, the most interesting and instructive results. In igneous rocks we can see clearly and determine the crystals of which they are composed, and can also determine the order of their crystallization. Thus, quartz in granite, syenite, etc., often appears to have been the last to crystallize, as we see it enveloping the other crystals of felspar, etc., which are, as it were, embedded in it. As a rule, the harder the rock, the easier is it to prepare these microscopical sections. Mr. Sorby has succeeded in preparing sections of soft chalk, of coal, and of slate, cut at right angles to the cleavage, which are triumphs of manipulative skill. These rock-sections can be obtained ready cut, or your own specimens will be prepared for you at a moderate charge by most of the dealers in microscopic slides. We have had some very fine specimens from Mr. Wheeler, of 48 Tollington Road, Holloway, and also from Mr. Gregory.

Very little has hitherto been written in English on this subject. There is a paper by the late David Forbes in the *Popular Science Review* for October 1867, and another in the number for January 1875 by the Rev. J. M. Mello. Mr. Sorby's first paper appeared in vol. xiv. of the *Geological Society's Journal* (1858), and his recent address is published in the *Monthly Microscopical Journal.*

But to return to our *gneiss.* If we prepare a thin section of it in the above manner, we shall probably be able at once, with the naked eye, to distinguish the irregularly striped appearance due to the layers of white quartz, greyish felspar, and

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dark mica, which it presents when held up to the light. *Gneiss* is a good example of a true metamorphic rock. In several regions we can pass from slate to schist, and then on to gneiss, and, lastly, granite, each bed shading off into the next, so as to render it impossible to lay one's finger on the junction. If we imagine a silicious slate exposed to a moist heat under pressure, we shall have conditions under which the mineral substances would be free to rearrange themselves according to their chemical affinities, and to segregate along lines. Such was probably the origin of the rock termed gneiss.

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CHAPTER IV.

PRACTICAL WORK AMONG CAMBRIAN ROCKS.

BEFORE we can discuss the Cambrian beds, we must state clearly what rocks we include under that term; for, unfortunately, there is much contention between the followers of two great geologists—both now, alas! no more—as to what rocks should be called *Cambrian* and what *Silurian*. Up to the year 1833, the *Older Palæozoic Rocks* were regarded as almost hopeless ground. Such was considered to be their complexity and difficulty, that they had been very assiduously let alone by the brethren of the hammer. But in that year two men were at work in Wales and Shropshire, whose labours were destined to reduce the whole to order, and to make clear the relationships of these old rocks. These two men were Roderick Impey Murchison and Adam Sedgwick, denominated later on by his pupils 'Father Adam,' and who, indeed, had a good claim to that title as far as much of English geology is concerned.

Murchison walked over and tried his hammer on all the old rocks of Shropshire and the neighbouring Welsh counties, while at the same time Sedgwick was similarly investigating the rocks of North Wales. In 1835, Murchison announced that he had discovered an immense thickness of slaty, gritty, and

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schistose beds, containing certain fossils; and as the region they occupied was formerly the home of the Silures, a tribe of ancient Britons, he called these rocks *Silurian*. He followed this up by the publication of that grand book, the *Silurian System*, in 1839, dedicated to his eminent associate Professor Sedgwick, and of which the fifth and latest edition was published in 1872.

But Sedgwick was not idle all this time. He too discovered the relations to one another of a vast series of rocks in North Wales, for which in 1836 he proposed the name of *Cambrian*, from Cambria, the old name for Wales.

Now, if all these old rocks noted by Sedgwick and Murchison had been regular and orderly in their arrangement, with an even easterly dip and north-east and south-west strike, such as we find on the whole to prevail in the secondary strata, then all would have gone well, and Sedgwick's beds, being to the north-west of Murchison's, would have been found to underlie them, and to be altogether of an earlier age.

Such they supposed at first to be the case; but when the two friends—for Murchison and Sedgwick were very intimate at this time, and indeed continued to be so for many years after, travelling abroad together, and writing papers in conjunction—came to connect their work, and to map it out more exactly, it was found that the upper portion of Sedgwick's Cambrian beds corresponded to, and were identical with, the lower divisions of Murchison's Silurian system.

Each of the great geologists held to his own. But Murchison did more; finding, as years went on, that there was no satisfactory *base* to his Silurian rocks, no clearly marked line of unconformity or

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of difference in the fossils, he gradually annexed the Cambrian rocks of Sedgwick, until at last he left in the Cambrian system only the bottom rocks. In the following table the claims of Murchison and of Sedgwick will be clearly seen :—

Upper Cambrian (*Sedgwick*).	Bala and Caradoc beds. Llandeilo flags. Arenig or Skiddaw group.	Lower Silurian (*Murchison*).
Middle Cambrian (*Sedgwick*).	Tremadoc slates. Lingula flags.	Primordial Silurian (*Murchison*).
Lower Cambrian (*Sedgwick*).	Menevian beds. Longmynd group.	Cambrian (*Murchison*).

The column in the centre shows the division into beds, as to which all geologists are agreed. On the left hand we see Sedgwick's classification of them, and on the right hand Murchison's.

Now Sir Roderick Murchison, being a rich man, and possessed of great social influence, being, moreover, made Director-General of the Geological Survey of the British Isles, and being further undoubtedly a man of great abilities, was enabled during his lifetime to carry the day, and to secure the assignation of the term Silurian to, at all events, the *Upper Cambrian* of Sedgwick. It would have been well if he had rested content with this; but, in his desire to find what he regarded as a satisfactory base to his system, he desired also to include in the Silurian formation the *Middle* Cambrian of Sedgwick, and for this he cannot be said to have made out a satisfactory case. Sedgwick felt the matter deeply, and replied vigorously in his *Synopsis of the Classification of the British Palæozoic Rocks*, 1855, and the *Catalogue of the Cambrian and Silurian Fossils in the Geological Museum of the University of Cambridge*, 1873.

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Sir Roderick died in 1871 (aged 79), and Sedgwick in 1873 (aged 88), and it may be mentioned that each held to the last his own ideas on the classification of the Palæozoic rocks.

In such a case as this, what is to be done? Sir Charles Lyell, in his admirable text-book, the *Student's Elements of Geology*, has endeavoured to steer a middle course, and has drawn the line of separation between the Arenig or Stiper-stones group and the Tremadoc slates, assigning the former to the Silurian, and the latter to the Cambrian system. Now this seems a fair division, and it is the one we shall adopt; for it leaves in the Silurian those rocks of Sedgwick's which were found to be *identical*, being mere repetitions, owing to faults and the rolling over of the strata, of Murchison's Lower Silurian beds of Shropshire, while on the other hand it ignores Murchison's claim, based on fossil evidence, to remove the lower limit of the Silurians to an indefinite point downwards.

All this dispute arose from the want of a good line of demarcation between the two series. Our rocks have been separated into formations which were usually bounded by lines of unconformity above and below, accompanied with great change in the fauna and flora as evidenced by the fossils.

But as our knowledge increases, as other parts of the world come to be geologically examined, these gaps will be bridged over more or less, and the significance of our names will be limited to certain areas, although as a means of classification they will, of course, always be indispensable.

We shall, then, consider the following rocks as Cambrian :—

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Upper Cambrian (5000 feet.)	Tremadoc slates (Wales) and Malvern shales.
	Lingula flags (Wales) and Hollybush sandstone (Malverns).
Lower Cambrian (18,000 feet).	Menevian beds (St. Davids, in S. Wales).
	Llanberis grits and slates (N. Wales, St. Davids, etc.).
	Harlech grits and Barmouth sandstones (N. Wales).
	Longmynd rocks (Shropshire).

The Longmynd Hills form a round-backed ridge of quartzose sandstone about two miles west of Church Stretton, in Shropshire. Their extreme

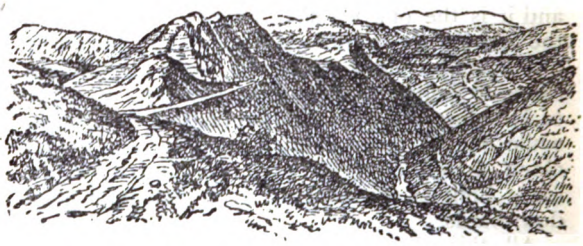

Fig. 9. The Longmynd Hills, Shropshire.

height is 1674 feet. In hilly or mountainous regions of old rocks we usually get very fair sections exhibited in the brooks and stream courses, which cut gullies and channels in the sides of the hills. If we walk along the brook which runs down the western side of the Longmynd to Church Stretton, we shall come first to some thin schistose beds of clay slate, and then to the beds of indurated finely-laminated sandstone which compose the mass of the hills. All these beds dip at a high angle to the W.N.W., and, in accordance with the rule that '*the strike is always at right angles to the dip*,' we see

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at once that the range extends from N.N.E. to S.S.W. Trying our hammer on the rocks, we soon find that they will still split, though not readily, along the lines of bedding. Soon we secure specimens with a rugose, wavy surface. In these we have, in fact, indications of the old sea-shore; it is the *ripple-mark* so familiar on the sands of our coast. In the Scientific Loan Collection at South Kensington, in 1876, there was a capital model by H. C. Sorby, Esq., F.R.S., which we had the pleasure of using, in a lecture delivered there, to illustrate the manner of production of this same ripple-mark. The model showed the movement of the particles (represented by white discs) at the top and at the bottom of a wave which had advanced from deep to shallow water, so as to give rise to ripple-marks. At the surface, the water particles move nearly in circles, being represented in the model by white discs attached to each alternate wheel. At the bottom, owing to the retardation produced by friction, the water moves backwards and forwards, drifting the sand forwards when the crest of the wave is passing, and backwards when the trough is passing. The figure described by the lower water particles is also represented by the motion of white discs. In the model, the motion is produced by turning a handle causing small eccentric wheels to act on pieces of brass fixed at one end, and carrying white discs at the other.

In the sandstones of the Longmynd we not only find indications of wave-washed shores, of the rise and fall of tides, in the ripple-marks we have described, but facts which tell us of the existence of the sun as well as of the moon at that period, and yet more of the *life* which existed on those sandy beaches.

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All this we owe to the keen eye of Mr. J. W. Salter, prince of palæontologists, who in 1856 fairly laid siege to the Longmynd, tackled it resolutely for one month, and made its rocks yield up their secrets.

The straight filled-in crevices which cross the hard blocks of sandstone and grey schist are *sun-cracks*, produced by the drying up of the wet sand under the sun's rays during the period of low tide. We may see just such cracks if we examine in the summer the clayey bottom of any dried-up pool.

But what are these little tubes, always occurring in pairs? Following the Lyellian plan, and looking

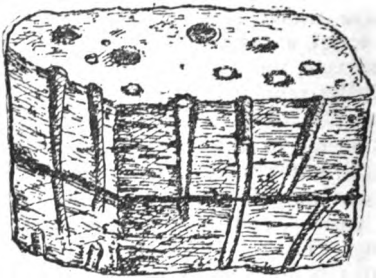

Fig. 10. Worm Burrows (*Arenicolites linearis*) in sandstone.

for something similar at the present day, we at once recognise in these hollows the burrows of marine worms, the common *Arenicolæ* of our coasts. To these ancient burrows Mr. Salter gave the name of *Arenicolites didymus* and *A. sparsus*, distinguishing in them two species. These are admirably figured in Plate 2 of Mr. Baily's excellent work, *Figures of Characteristic British Fossils*, *Van Voorst*, 1875, of which only the first volume, con-

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taining the principal *Palæozoic* fossils, has yet been issued.

On Callow Hill in the Longmynds, Mr. Salter also found what he believed to be a fragment of a trilobite, and named *Palæopyge Ramsayi*, but its organic origin has been questioned.

The Harlech Grits are of a greenish tint, and interstratified with slates. On their surfaces we find the pittings ascribed to the action of *rain*, with corresponding projections on the next layer above. These 'fossil raindrops' are better shown in newer beds, but in the meantime the student should watch the effect of a sharp shower on any half-dried muddy or sandy surface, and should cut out a square and endeavour to preserve it, to place in his cabinet side by side with these old, old markings due to the same cause. The same thing may be done with worm-burrows, the footprints of birds, frogs, etc. Such specimens are most interesting and convincing when exhibited in illustration of their ancient prototypes.

The Llanberis Beds include the famous slates of Penrhyn and Llanberis, immense quantities of which are annually quarried and sent to all parts of Great Britain, and even to America. The Penrhyn quarries yield about 120,000 tons of slates annually. The slates are either purple or green in colour, and often have a variegated appearance. The whitish or light-green spots, which are so familiar to us from their occurrence on our school slates, are mostly due to the abstraction from that particular portion of the rock of the oxides of iron which form the principal colouring agents in all rocks. Very often this iron is found concentrated in a small central nucleus of the spot (not always visible, since the section may not pass through the

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centre), or else it seems to have passed outwards, forming a darker ring round it.

In the purple slates we get an excess of the sesquioxide of iron (Fe_2O_3), while in the green slates the greater part is in the state of protoxide (FeO). These blotches were produced previous to the production of the phenomenon known as slaty cleavage, which we have now to describe, and the conversion of purple into green slates can be shown to be often due to intrusive masses or dykes of volcanic rock, by which the slaty beds are often traversed.

Slaty Cleavage.—Von Cotta defines clay slate as 'a compact fissile rock of a dull blue-grey, bright red, purple, green, or black colour; consists chiefly of clay; sometimes with accessory admixtures of quartz, mica, and other minerals. The slaty cleavage is usually very perfect, and only occasionally coincides with the original lamination of the rock.'

Now workmen in general speak of any stone which is used for roofing purposes as 'slate,' thus including under that term the thin-bedded limestones of Stonesfield, Collyweston, etc. But this use of the term is incorrect, and it is properly applied only to those rocks which, by the action of a certain kind of metamorphism, have now the property of splitting into thin plates, usually, though not necessarily, inclined at a high angle to the original planes of bedding.

The phenomenon of slaty cleavage was long esteemed a question difficult of elucidation. Professor Sedgwick ascribed it to the action of crystalline forces. Mr. R. W. Fox and Mr. R. Hunt, in 1837, showed that lamination could be produced in clays by long-continued voltaic currents; now we

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know that such electrical currents are continually circling round the earth. It was reserved, however, for Mr. Sorby and Professor Tyndal to give a full and satisfactory explanation. Slaty cleavage has simply been produced by immense and long-continued pressure, the rocks at the same time being probably much heated and percolated by water. If this be the true reason, we ought to be able to produce cleavage artificially by submitting substances to great pressure. Mr. Sorby mixed fragments of blue paper with pipeclay, crushing it up into a heterogeneous mass, so that the paper particles lay in all directions. After placing this under pressure, the paper particles were found lying flat and parallel to the pressure, and the mass had a flaky structure. Afterwards Mr. Sorby availed himself of Brockedon's patent, by which plumbago dust is compressed by a hydraulic press into a compact mass for the manufacture of lead pencils. He found the compressed plumbago or graphite to have a perfect cleavage *at right angles to the pressure.* Professor Tyndall submitted wax to similar pressures, and was enabled thereby to cleave it into plates no thicker than writing-paper. He has described this in an article on 'Slate' in his book entitled *Fragments of Science.*

We explain the effect by supposing that, under the influence of pressure, the particles of the substance are squeezed or set themselves parallel to it, thus conferring a symmetrical structure on the mass, in virtue of which it splits with great facility. Further, the finer and smaller are the particles, the more perfect is the cleavage we are enabled to produce, for they can yield to the pressure with greater facility. This has also been the case in rocks—the fine-grained muds have been converted

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into slates; but there are many sections where no such cleavage is seen in beds of limestone and sandstone interbedded with them. Where, however, are we to look for the agent capable of exerting enormous pressure over great regions, on beds of shale, etc., hundreds of feet in thickness?

In 1829, the great French geologist, Elie de Beaumont, called attention to the effect on the crust of the earth of the secular cooling of the globe, and this theory has since been enlarged until it has finally been applied by Mr. Robert Mallet to the explanation of all the phenomena of volcanoes and earthquakes.

It is plain that a *cooling* globe is a *shrinking*, a *contracting* globe. In its efforts to conform to the contracting nucleus, the crust will suffer great contortions in those spots which are weakest, the side-thrust thus exerted being tremendous. From this results the elevation of mountain chains, etc., and among other things the conversion of soft shales into indurated and cleaved slates. In the fossils often contained in slates we get indications of this; they are so squeezed, distorted, and elongated as often to be hardly recognisable. Professor Ramsay, in his *Geology of North Wales*, cites a section at Llyn Padarn, where is shown a conglomerate consisting of pebbles in a slaty matrix, the whole being affected by slaty cleavage. Now, when this conglomerate was formed as an old shingle bed, the pebbles would all lie with their longer axes parallel to the planes of bedding, but such has been the force of the pressure producing cleavage, that the pebbles have been elongated in the direction of the cleavage planes, and now lie obliquely to the planes of bedding.

Bedding Planes.—These are the lines along which deposition of sediment originally took place, and

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along which the rock would and does split, if it has not been subject to subsequent metamorphic action. In sandstone these bedding planes are often covered with flakes of mica; for, on the discharge at low water of the contents of a river into the sea, the particles of quartz, etc., being heavier, would sink first, while the flat plates of mica would descend but slowly through the water, and would form the top layer. We can usually distinguish the bedding planes by the variation in colour of successive layers, —the *stripe*, as it is termed; also by the variation in texture, it being rare that sediment of precisely similar nature, specific gravity, and composition continued to be uninterruptedly deposited in one spot.

The Menevian Beds.—We have already alluded to the central metamorphic pre-Cambrian ridge of the peninsula of St. Davids. Now resting upon this ridge we find beds of sandstone (probably of the same age as the Harlech grits), and then dark shales 500 or 600 feet thick. To the latter the term Menevian has been applied, from *Menevia*, the Roman name for St. Davids.

In these old rocks the researches of Messrs. Salter and Hicks have brought to light a comparatively rich fauna, and here we first meet with the well-known fossils called trilobites.

What is a Trilobite?—If we look at any ordinary specimen of this fossil, the origin of the name is easily seen in the three lobes into which the body is longitudinally divided. We see also a transverse division into a head, or *cephalic shield*, usually bearing prominent eyes, the *thorax* composed of a variable number of thoracic rings or segments, and, lastly, a tail, or caudal shield, or *pygidium*.

The first notice of trilobites occurs in the *Philosophical Transactions* for 1698, and is from the

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pen of Dr. Lhwyd, who calls attention to the 'regularly-figured stones lately found by him,' which he thought to be 'the skeletons of some flat fish,'

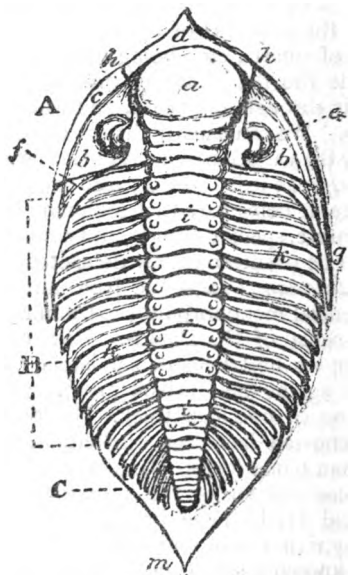

Fig. 11. Parts of a Trilobite, after Baily (*Phacops caudatus*):—A. Head or cephalic shield: (*a*) Glabella; (*b*) Sides or cheeks; (*c*) Cheek margin; (*d*) Front margin; (*e*) Eyes; (*f*) Posterior margin; (*g*) Posterior angles or cheek spines; (*h*) Facial sutures or divisions of the head. B. Thorax, thoracic rings, or segments of the body; (*i*) Axis or central portion; (*k*) Pleura or side lobes. C. Pygidium or tail, caudal shield; (*l*) Margin; (*m*) Mucro.

but remarks that 'not these or any other marine terrestrial bodies were really parts of animals.' In fact, he held the same view as Dr. Plot, who, in

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his *Natural History of Oxfordshire*, 1677, attributes all fossils to 'a plastic virtue latent in the earth.' From the plate accompanying Lhwyd's article, we can recognise that one of his 'regularly-figured stones' was the well-known trilobite *Ogygia Buchii*. Of the hundreds of notices of trilobites which have since appeared, there are three of chief value:—Burmeister's *Organization of Trilobites*, translated by Bell and Forbes for the Ray Society, 1846; Barrande *on Trilobites*, 1853; and Mr. Salter's *Monograph on Trilobites*, commenced by him for the Palæontographical Society in 1864, and which, in consequence of his lamented death, will be completed by Mr. Henry Woodward, of the British Museum.

From the long-continued and patient investigations of these authors and others, we learn that trilobites belong to the sub-kingdom *Annulosa*, division *Articulata*, class *Crustacea*, order *Trilobita*. This order is entirely extinct, but in the king-crabs of the West Indies and in our common wood-lice we see creatures somewhat similar. The nearest living ally of the trilobites is an isopod called *Serolis*, which was dredged up by the late Professor Agassiz off the coast of Patagonia.

Trilobites were undoubtedly marine creatures, living probably on muddy bottoms in shallow water near coast-lines. In many species the thorax was so flexible that the trilobite could roll itself up like a hedgehog. In one of the finest private collections of trilobites in the British Islands, viz. that of Mr. E. Hollier of Dudley, there are some exquisite specimens of *Calymene Blumenbachii*, the characteristic Upper Silurian trilobite, preserved fossil in this probably defensive attitude.

The appendages of trilobites, their legs, antennæ, etc., were probably soft and delicate. In 1870,

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Mr. Billings, of the Geological Survey of Canada, described to the Geological Society (vol. xxvi. p. 479) a specimen of *Asaphus* which had traces of eight legs preserved, and Mr. Woodward has since been able to confirm this. Trilobites vary much in size, from *Agnostus*, about $\frac{1}{8}$th of an inch in length, to *Paradoxides*, 22 to 24 inches long.

In attaining the adult state they went through a series of metamorphoses, which have been most carefully worked out by M. Barrande. They probably cast their integument at intervals, as our crabs and lobsters do, and this would account for the many fragments we find. In some genera, especially *Phacops*, the cephalic shield seems to have been slightly jointed on to the thorax, so that when the trilobite died the two parts often became detached, and we find the head in one place and the rest of the body in another.

The earliest known trilobites occur in the very lowest beds of the Lower Cambrian series, and belong to the six genera—*Agnostus*, *Microdiscus*, *Palæopyge*, *Paradoxides*, *Plutonia*, and *Conocoryphe*. They continue to increase in number until they fairly swarm in Upper Silurian rocks, and then gradually die out, the last genus found being *Phillipsia*, in the carboniferous limestone. Thus they are exclusively Palæozoic fossils.

The remaining Cambrian beds we must dismiss very briefly. The *Lingula Flags* were so termed in consequence of the discovery in them by Mr. Davis, in 1845, of a brachiopod shell, *Lingulella Davisii*. They occur near Tremadoc (N. Wales), and are overlaid by the *Tremadoc Slates*. These beds are represented on the western side of the Malvern Hills by the *Hollybush Sandstone* and *Malvern Shales*.

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CHAPTER V.

PRACTICAL WORK AMONG SILURIAN ROCKS.

THE following is a complete table of the divisions of the Silurian rocks of Wales and England, together with their equivalents in the Lake district:—

	Wales and West of England.	*Lake District.*
Upper Silurian.	Ledbury Shales.	
	Tilestones, Downton Sandstones.	
	Upper Ludlow Beds, . .	Kirkby Moor Flags.
	Aymestry Limestone.	
	Lower Ludlow Beds, . .	Bannisdale or Ireleth Slates.
	Wenlock (& Dudley) Limestone,	
	Wenlock Shale, . . .	
	Woolhope (& Barr) Limestone.	
	Denbighshire Grits, . . .	Coniston Grits and Flags.
	Tarannon Shale or Pale Slates.	
	Upper Llandovery Rocks (or May Hill Sandstone).	
Lower Silurian.	Lower Llandovery Rocks.	
	Caradoc or Bala Beds, . .	Coniston Limestone.
	Llandeilo Flags, . . .	Green Slates and Porphyries.
	Arenig or Stiper Stones Rocks,	Skiddaw Slates.

It is obvious that it would be impossible here to treat separately of each of these subdivisions,

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and we must consider the formation broadly as a whole. Glancing at any geological map, we see that the Silurians occupy much of the east and north-east of Wales; they stretch thence into the border counties, especially Shropshire, and are again brought up in patches in the South Staffordshire coal-field, at Walsall, Sedgely, and Dudley. In the centre of the Lake district, the green slates and porphyries occupy the region around Skiddaw, whilst the higher beds come in farther south, between Morecambe Bay and the northern end of Windermere. The ashy slates, grits, and syenites of Charnwood Forest, in the very centre of England, are also in our opinion of Silurian age, perchance the equivalents of the green slates and porphyries. They seem to form an extension of the Pennine axis of upheaval, although their anticlinal axis had probably been formed previously.

The working out and mapping of the Silurian rocks of Wales was among the earliest tasks of the Geological Survey, and it taxed all the energies of their best men. Ramsay, Beete Jukes, Aveline, and Selwyn did most of the work, and from Jukes' *Letters* of that period we get an interesting picture of the life and difficulties of a geological surveyor. The following extract is from an address by Professor Jukes to the Geological Society of Dublin in 1855:—'I had once been working hard for about five weeks, trying to understand and delineate on the one-inch map a complicated bit of mountain ground a few miles south of Conway, in North Wales. It was made up of interstratified slates, sandstones, and felstones, with large and irregular masses of intrusive greenstones, the exposed parts of each being frequent but not continuous. Many a weary day had I climbed the sides and clambered

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along the crags of a hill some five or six miles in length by two or three in breadth, and the highest peak of which was not more than 1800 feet above the sea, trying in vain to reduce to order the seemingly endless complexity of its structure, and having at length on the map as curiously complex a patchwork of incongruous colours and unnatural forms as Punch, had he turned geologist, could have devised, when one evening, as, after a hard day's work, I was descending a steep bit of ground, almost in despair at all my labour seeming to be thrown away, I hit upon the clue to a great fault or dislocation. I had only time then to verify the observation, but it gave me at once the solution of all the puzzle, and in two or three days I was enabled to map the whole district with as near an approach to accuracy as the scale of the map admitted of. The country was chopped up by a series of large parallel faults that were quite easy to be seen when once the clue to one of them and its bearings were obtained, but which there was nothing to render *a priori* probable, and which could not have been discovered without that thoroughly exhaustive process of examination which I was enabled to apply to the district. I have ever since regretted that, in my haste and joy at acquiring a right notion, I obliterated all my former work from the map which contained it; for I should have been glad to preserve it now as a curious instance of the contrast between laborious hypothesis and the simplicity of natural truth!'

Silurian Fossils.—Let the student who wishes to get a good idea of the old Silurian sea-floor pay a visit to the Wren's Nest Hill in the neighbourhood of Dudley. Here the beds of Wenlock limestone have a quaquaversal dip from the central

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boss or mass of the hill—that is, they form part of an elevated dome-like mass, from which they slant outwards in all directions at a high angle. The best limestone has been almost worked out for burning, but on the great bare faces of rock which have thus been left exposed, we find, literally, myriads of fragments of organized beings. Portions of trilobites, corals, shells, such as *Orthis*, *Orthoceras*, *Rhynconella*, etc., form actually the greater part of the rock. The best plan is to be provided with a stout hammer and chisel, and then to get a friend to let you down the sloping face from above by means of a cord tied round the waist. Choice specimens may then be bagged; but, for the ordinary visitor, a walk along the base will probably be sufficient. In the neighbourhood of Dudley, numerous men make a large part of their livelihood by the search for fossils. Perfect specimens even of the 'Dudley Locust' (*Calymene Blumænbachii*) are by no means common; and the stranger should be careful in purchasing from these 'Fossil Jacks,' as they are called, or he may get the head of one species of trilobite artfully cemented on to the tail of another.

Graptolites are exclusively Silurian, and are the most characteristic fossils of the formation. The name is derived from *grapho*, I write, and *lithos*, a stone, from their resemblance to hasty scribblings on a slate. They are the skeletons of composite animals which in life were united by a common fleshy trunk, protected by a delicate horny sheath. They were free floating creatures, living in the open sea, and form the extinct sub-class *Graptolitidæ*, of the division *Hydrozoa*, of the sub-kingdom *Cœlenterata*. The living organisms most resembling them are the 'sea-firs,' branched hydroid zoophytes,

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which are constantly mistaken for sea-weed by visitors to our sea-sides. It may be noted of

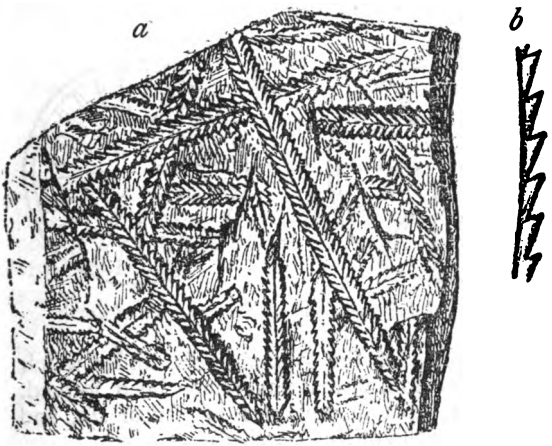

Fig. 12. (*a*) Slab of Slate covered with impressions of *Graptolites*; (*b*) Portion of Graptolite magnified.

graptolites, that they occur usually in black shales, that they are first met with in the Arenig Group, and are much more abundant in Lower than in Upper Silurian rocks. Professor Nicholson is the chief authority on the subject.

Corals belong to the division *Actinozoa* of the sub-kingdom *Cœlenterata*. They may be either simple and separate, when they are usually like a cup or cornucopia in form, or compound and clustering together, often forming thick rock masses with their skeletons. When we look down into a coral, we see it divided by vertical partitions or *septa* (singular *septum*), some of which extend

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nearly to the centre. Now, all the corals found in *Palæozoic rocks* have these septa arranged in sets or multiples of *four*. They form the order *Rugosa*.

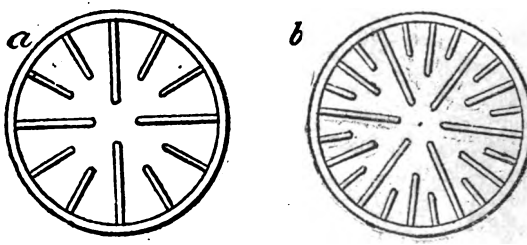

Fig. 13. (*a*) Palæozoic and (*b*) Neozoic types of Corals.

The corals of the *Neozoic rocks*, under which term we include all that have since been formed, have their septa in multiples of *five* or *six*, and form part of the order *Zoantharia*.

Lamp Shells are very numerous, and of varied forms. The term 'Age of Brachiopods' has, in fact, been used to designate the Silurian period as a whole.

First Appearance of Vertebrates.—In 1840 Sir R. Murchison found a 'bone-bed' in the Upper Ludlow beds, just below the Downton Sandstone. It is a layer one or two inches thick, formed of a matted mass of bony fragments. It is well shown in Ludford Lane, and on the slopes of Whitcliffe, near Ludlow. At Norton, five miles north of Ludlow, Mr. G. E. Roberts describes it thus: 'In a narrow lane leading from the main road to a farm-house, and forming the roadway beneath our feet, was a solid pavement of bone-bed, lying in its natural position so nearly horizontal, that, by

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inserting our stoutest pick beneath the uppermost layer and exerting some leverage force, we could raise flags nearly as large as a London flagstone. It thus formed a naturally-paved cartway to the farm, and had evidently been left as such, by reason of its superior hardness to the shaly sandstones above and below it. I almost wish I could say that we left this *Via Deliziosa* as smooth and unbroken as we found it; but, alas! scientific ardour would not be restrained, and our annexation of four-inch specimens strewed this excellent pathway with its macadamized fragments.' The contents of this bone-bed are chiefly fragments of crustaceans, but we also get teeth, spines, and scales of three genera of fishes, viz. *Thelodus*, *Sphagodus*, and *Plectrodus*. These remained the earliest vertebrates known until the year 1859, when Mr. J. E. Lee found a specimen of the bony head-shield or buckler of a fish, which has been named *Pteraspis Banksii*, in the Lower Ludlow shales, at Church Hill, near Leintwardine, in Shropshire. It belongs to that group of *ganoid* fishes now represented by the sturgeon, gar-pike, etc.

To the above brief notes on the leading features of the life of Silurian times, we may add that in Upper Silurian beds we get the first known remains of true *land plants* belonging to the *Lepidodendron*, which was afterwards to play so important a part in the Carboniferous forests.

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CHAPTER VI.

THE OLD RED SANDSTONE AND DEVONIAN ROCKS.

THIS double name is applied to a series of beds having a maximum thickness of 10,000 feet, which rest upon the Silurians, and are in turn overlaid by Carboniferous strata. The first name —*Old Red Sandstone*—indicates the prevailing lithological character of the beds, their usual colour, and their *age;* for there are other beds of red sandstone of later date, which we find *above* the Carboniferous rocks, and to which the name of *New Red Sandstone* is applied.

In Scotland, these beds of *Old Red* occupy the northern side of the great valley between the Lammermoor Hills on the south and the Highlands on the north, and they run along the east coast at intervals to beyond Cromarty and the Moray Firth. Here the labours of Hugh Miller first exposed those wonderful fossil fishes which form the main feature of the life of this period; and in his book, *The Old Red Sandstone,* he thus describes his first 'find':—'The slab opened with a single blow of the hammer, and there, on a ground of light-coloured limestone, lay the effigy of a creature fashioned, apparently, out of jet, with a body covered with plates, two powerful arms articulated at the shoulders, a head as entirely lost in the

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trunk as that of the ray or sun-fish, and a long, angular tail.' It was the *Pterichthys*, or winged fish, so named from the wing-like appearance of the pectoral fins, and was covered with enamelled plates and scales, forming one of the group of *ganoid* fishes, remarkable for their unequally-lobed tails and the shining covering of bony plates with which they are armed. Among the Old Red fishes of this group are *Pteraspis* (shield-winged), *Cephalaspis* (buckler-headed), and *Coccosteus* (berry-bone), the latter having its enamelled plates studded with berry-like tubercles. Other remarkable forms are *Holoptychius* (all-wrinkle), with corrugated scales, and *Osteolepis* (bony-scale).

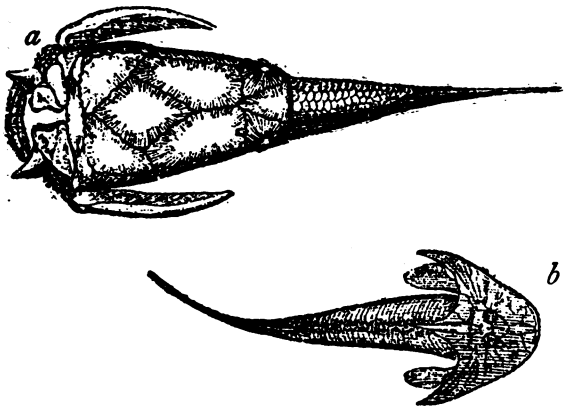

Fig. 14. Fishes of the Old Red Sandstone :—(*a*) *Pterichthys cornutus*, from Moray ; (*b*) *Cephalaspis Lyelli*, Glamis.

The living ganoid fishes do not number more than forty species. They are all fresh-water, with

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the exception of the sturgeon, which occasionally visits the sea. They include the bony pike (*Lepidosteus*) of North America, and the *Polypterus*, living in the Nile and the rivers of Senegal.

Another most interesting recent ganoid fish is the *Ceratodus*, whose teeth occur in the New Red Sandstone, but which has lately been found by Mr. Gerard Krefft, curator of the Sydney Museum, to be still living in the rivers of Queensland. The *Lepidosiren* of South America and Africa is an allied genus.

Those who would acquire a detailed knowledge of the subject must consult, in addition to Hugh Miller's works, Agassiz' splendid *Poissons Fossiles*, Murchison's *Siluria* and his *Geology of Russia*, together with the *Monograph*, by Messrs. Powrie and Ray Lankester, now in course of publication by the Palæontographical Society.

In the Lower Old Red Sandstone a very large and remarkable crustacean occurs, known as *Pterygotus Anglicus;* the fossils found in the same strata, and named *Parka decipiens*, are probably the egg-packets of this huge crayfish-like creature. Land plants, including fragments of a coniferous tree, are also common. The best-known Scottish localities for Old Red fossils are the yellow sandstones of Dura Den in Fife, Gamrie in Banffshire, and the paving-stone quarries near Arbroath.

In the south of Ireland, beds of the same age occur in the counties of Cork, Kilkenny, etc. From Kiltorkan, Mr. Jukes describes the following fossils, found about the year 1850:—'They were certainly a very remarkable group; fronds, two feet across, of a large fern, since named *Adiantites Hibernica;* several stems of *Stigmaria*, *Calamites*, and *Lepidodendron*, or other similar plants; and a shell like

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our *Anodon*, three inches across, to which Forbes afterwards, in spite of my remonstrances, insisted on affixing my own inharmonious name as a specific designation.' This is the shell known as *Anodonta Jukesii;* it is the only shell which has hitherto been discovered in the Old Red Sandstone of the British Isles, and, as noted above, resembles our fresh-water mussel in appearance.

In England we get patches of sandstones and conglomerates of Old Red age in the Lake district of Cumberland and Westmoreland. Professor Ramsay has pointed out that these conglomerates, with similar beds in the Old Red near Caithness, are almost certainly relics of ice-borne boulder beds, thus giving evidence of the existence of a Glacial Epoch at that remote period.

The main English tract of Old Red, however, extends from near Bridgnorth, in Shropshire, all through Hereford and Brecknock, sending out a narrow band westwards to Milford Haven, and reaching southwards to Cardiff and Chepstow. Here it usually yields a loamy, fertile soil, on which numerous apple orchards are situated. Bands of nodular or concretionary limestone occur; these are known as 'corn stones.' In the railway tunnel near Ledbury, the junction of the Old Red with the Upper Silurian rocks was well shown, and the two formations were there seen to be *conformable* one to the other—that is, the passage appeared to be a gradual one, the strata being parallel with each other, and an intermixture of the fossils special to each being observed near the point of junction. In *Siluria*, Sir R. Murchison tells us that 'the grandest exhibitions of the Old Red Sandstone in England and Wales appear in the escarpments of the Black Mountain in Here-

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fordshire, and in those of the loftiest mountains of South Wales, the Fans of Brecon and Carmarthen —the one 2860, the other 2590 feet above the sea. In no other tract of the world visited by me have I seen such a mass of red rocks (estimated at a thickness of not less than 10,000 feet) so clearly intercalated between the Silurian and Carboniferous strata.'

Whitbach, near Ludlow, is a good locality for fossils, and Leominster, Kingston, and Cradley may also be mentioned. The fossils found are similar to those which occur in Scotland; perfect specimens of fish must, however, not be expected, but rather the detached bony scales and plates, every one of which, however, will reveal to the experienced eye the genus to which it belongs. The finding of a good fossil is a pleasurable occurrence even to the uneducated eye; but when we have gained experience and the power of discrimination, it is then difficult indeed to exaggerate the inward satisfaction felt when a blow of the hammer reveals to our eyes some new and strange form—something, perhaps, which will help to fill up a gap in the scheme of life. Such 'finds' often tempt the youthful geologist to outward manifestations of pleasure. How well do we remember the war-dance executed by an old pupil on a narrow shelf we had hewn out to stand upon, half-way up a shaly cliff! how magical was his disappearance, and what a striking resemblance to a mud-clad navvy he subsequently presented!

The Devonian Type. — Crossing the Bristol Channel, we find, in Devonshire, a series of rocks which are also seen to rest upon Silurian strata, and to be surmounted by Carboniferous beds, but which have such a totally different appearance,

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and which contain such a dissimilar assemblage of fossils, that we may well hesitate before classing them with the Old Red Sandstones of which we have been writing. These beds of a fresh type stretch across North Devon and Somerset, from Barnstaple Bay through Exmoor Forest to the Quantock Hills. They dip southwards, passing under newer beds, and rise to the surface again in the south of Devon, near Torquay, and south of Dartmoor, Launceston, and Tintagel, and form all the south-west of Cornwall. They are, however, in this district, much interfered with, broken up, and altered by masses of igneous rock, which have burst through them, forming granitic bosses, so that their relations cannot here be well studied.

These beds of the south-west of England were named *Devonian* by Murchison and Sedgwick in 1836, partly from their own researches, and partly from the fact ascertained by Lonsdale, then secretary to the Geological Society, that 'the fossils of the South Devon limestones, collected by Mr. Austen and others, really constitute a Natural History group intermediate between those of the Silurian rocks and the Carboniferous limestone.'

Now at various points in North Devon, as near Lynton, and at Cockington in South Devon, we find beds of chocolate-coloured sandstone just like the Old Red beds of Hereford and Scotland. These are overlaid by masses of slaty and gritty strata. The slate quarries at Delabole are well known, and have been worked for a long period. The slates are blue or grey in colour, and are mostly shipped from Tintagel. Lastly, above these slates we get strata including thick beds of limestone, which are often so hard and crystalline in structure as to be entitled to rank as marble. These are

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worked near Plymouth, Newton Bushell, and Ipplepen, and are largely employed for columns, chimney-pieces, etc. Some, which are termed 'madrepore marbles,' are little else than compacted masses of coral, and polished specimens show beautifully the structure of the stony skeleton or corallium.

In the lower beds Mr. Pengelly and others have found scales, etc. of Old Red fishes, but the slates and limestones are full of evidence of their formation in a deep sea. Corals have already been noted, and *Favosites cervicornis* may be mentioned as common; of trilobites, *Bronteus flabellifer*, *Phacops latifrons*, and *Homalonotus armatus* are especially characteristic. Of bivalve shells, *Megalodon cucullatus* is common in the Plymouth limestone.

General Relations of Old Red Sandstone and Devonian Rocks.—Until lately it has been usual to consider the Old Red Sandstone as a fresh-water formation, and as having been deposited in great inland lakes at the same time when rocks of the Devonian type were forming in the open sea. Lately, however, doubts have been felt on this point. On the continent of Europe are deposits of Devonian type, full of marine shells, but containing also perfect specimens of Old Red Sandstone fishes. It is more likely that the Old Red Sandstone was a shallow-water littoral deposit, and that, if anything, it was formed at an earlier period than the Devonian slates and limestones, which in the south-west of England can be shown to rest upon it, and consequently to be of later date. The late Mr. Jukes was of opinion that, from long study of the Old Red Sandstone and the overlying Carboniferous slates in the south of Ireland, he had discovered that in Devonshire the strata we

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have been accustomed to consider as equivalent to the Old Red Sandstone of Scotland (though of marine formation), and to call Devonian, were really of Carboniferous age. He was successfully opposed at the time by Mr. Etheridge and others, but the question has now once more come to the front. In the *Geological Magazine* for October 1877, Mr. H. B. Woodward, of the Geological Survey, who knows the district well, points out that there is much to favour Jukes' view. The geological mapping of the south-west of England was done by De la Beche, who afterwards founded the Government Geological Survey. It was done roughly, and needs to be done again. When the whole district has been accurately and minutely mapped, it seems likely that the succession of rocks pointed out above—red sandstones, slates, and limestones —will be made evident, and also the fact that the limestones pass upwards into the Coal Measures. Then the fossil evidence must be worked over again and reconsidered, and this is a task in which the local geologist can render most important aid. 'Much of the collecting must be done afresh, and here is plenty of work for the resident geologist. We cannot have too many lists of fossils, recording the precise beds and localities; for by these means only can we determine the succession of life forms, and arrive at any conclusions as to the geographical distribution of the species.'

In conclusion, we may note that it is in the Devonian beds of North America that we meet with the first remains of insects.

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CHAPTER VII.

THE CARBONIFEROUS FORMATION.

THIS name is inseparably associated in our minds with the coal-seams, of which the upper portion of the formation is the chief repository; but it is worth remembering that 40 per cent. or nearly one-half of the limestone which forms the lowest division is also pure carbon.

Passage Beds.—This term is applied to any series of strata which forms the connecting link between two great formations, belonging exclusively to neither, but partaking of the characteristics of both.

The Lower Limestone Shale which occurs in South Wales, Somersetshire, etc., may be considered as a passage bed. At its base near Bristol we find a well-known bone-bed, containing numerous palatal teeth and spines of such fishes as *Psammodus*, *Cochliodus*, etc. Its thickness in the gorge of the Avon at Clifton is five hundred feet. In the south of Ireland, however, the passage beds between the *Old Red* and the Carboniferous rocks proper are very fully developed. We find in the promontories on the south-west of Munster magnificent sections, showing about three thousand feet of coarse sandstone, known as the *Coomhola Grit*, and these are surmounted by *Black Carboniferous*

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Slates two or three thousand feet thick. These are probably equivalent in part to the so-called Upper Devonian beds of the south-west of England. In Northumberland and Durham the base of the Carboniferous formation is constituted by a series of shales and sandstones, which Mr. Tate has named the *Tuedian Group*, and the equivalents of which in Scotland are known as the *Calciferous Sandstones.*

The Carboniferous or Mountain Limestone received the second of its two appellations from the fact that it usually occurs in hilly districts. It is a tough, greyish, crystalline rock, composed almost entirely of the fragments of crinoids, corals, and shells, and to all appearance was formed at the bottom of a tolerably deep and tranquil sea. Everywhere we find it bordering our coal-fields. Chemically it is composed of carbonate of lime ($CaCO_3$), but the lower beds are often *dolomitic*—that is, consisting of carbonate of lime plus carbonate of magnesia ($MgCO_3$). In South Wales it is about one thousand feet, and in the Mendip Hills three thousand feet in thickness. Northwards it thins out, so that Mr. Jukes supposed a land barrier or chain of islands to have run across England in those times, dividing the sea in which the Carboniferous limestone of Derbyshire, etc. was deposited from the area of the Mendips, etc. Of this old shore-line we get a remnant still existing in the rugged area of Charnwood Forest. Here, in the north-west corner of Leicestershire, and stretching into Derbyshire, we find eight isolated areas of Mountain Limestone brought up along lines of fault. At Breedon and Breedon Cloud there are extensive lime quarries, and the rock is dolomitic and impure; but at Ticknall, about two miles off, the ordinary

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pure, bluish carbonate of lime prevails. These are the nearest uncovered areas of Mountain Limestone to London, being only one hundred miles distant; and the whole region of Charnwood Forest is well worthy the attention of those who, living in the eastern or southern counties, wish to make personal acquaintance with the Palæozoic rocks. Northwards from this point the rock increases in thickness and purity, until in Derbyshire, between Buxton and Wirksworth, we get a mass of which the base is not seen, but which is probably not less than five thousand feet thick. Dipping northwards under newer beds, it reappears near Clitheroe, where it contains several beds of shale, and is known as the *Scar Limestone* of Phillips. Then we find more intercalated beds of sandstone and shale, until in Northumberland and Scotland the limestone district has become a valuable coal-field.

In Ireland nearly all the great central plain from Wicklow and Dublin to Galway and Sligo Bay is composed of the Mountain Limestone. North and south of this central mass there are a few detached coal-fields of small extent, which have been preserved by the strata being there thrown into synclinal curves; but over an immense area the whole of the upper portion of the Carboniferous formation, with its precious coal-seams, has been swept away by denuding agents in times past—another 'injustice to Ireland!'

Fossils of the Mountain Limestone.—Very frequently thin slices of crystalline limestones, when examined microscopically, show the rocks to be made up of the shells of Foraminifera, such as *Saccamina* and *Fusulina*. Often these may be recognised with the naked eye, as spheroidal particles standing out in relief on weathered

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surfaces. Whole beds of limestone are often formed of the remains of corals, of which *Lithostrotion basaltiforme* may be mentioned as specially characteristic. Among the *Mollusca* or shell-fish proper, we remark that brachiopod shells of the genera *Productus* and *Spirifer* are very common.

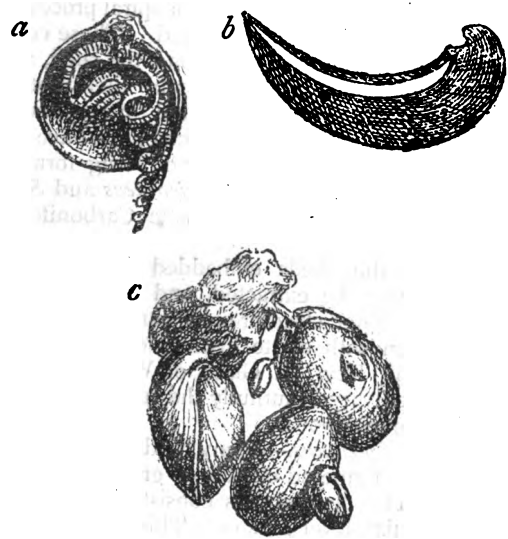

Fig. 15. (*a*) *Rhynconella psittacea*, showing the spirally-rolled labial appendages. (*b*) Section of *Productus Llangollensis*, to show the great thickness of the ventral, as compared with the dorsal valve. The unshaded part was occupied by the animal. (*c*) *Waldheimia cranium*, attached by means of the peduncle.

'What is a brachiopod?' is a question which has been answered by the great authority on that subject, Mr. Thos. Davidson, in the *Geological*

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Magazine for April and May of the year 1877. A brachiopod is a bivalve shell, having its two valves unequal in size and form, and denominated dorsal and ventral valves, because one protects the front and the other the back of the animal. They are familiarly termed *lamp shells*, from their resemblance to the old Roman lamps. In the interior we find two loops or spiral processes, to which fleshy arms were attached. These could in most cases be protruded beyond the shell, and, by creating currents in the water by their motion, served to obtain food and to aid in respiration. Over five thousand species of Brachiopoda have now been described, but the number of living forms is comparatively few. *Productus giganteus* and *Spirifera striata* are very characteristic Carboniferous forms.

Many of the shells embedded in crystalline limestones may be extracted, and even made to reveal their inner structure, by carefully treating the specimen with dilute hydrochloric acid. In this way the Rev. N. Glass of Wolverhampton has displayed very beautifully the internal 'spires' of various brachiopods.

Polishing Specimens.—Many hard rocks may, by polishing, be rendered objects of great beauty and interest. The first process consists in obtaining a tolerably flat, level surface. This may be done in two ways—either by rubbing the stone on a wooden tray lined with sheet lead and supplied with emery, or by working it on a slab of sandstone, using sand and water.

Next rub the face of the specimen with a piece of Water of Ayr stone, to be obtained at any marble works, using water only with it. This will leave a very smooth but dull surface. Finally,

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take a piece of wood, about the size of a knife-board, and tack on it, so as entirely to cover it, a piece of coarse, soft cloth. An ounce of putty powder (oxide of tin) should be obtained at a chemist's, and a little of this, moistened with water, placed on the centre of the board. The specimen is then rubbed on the cloth, the powder being renewed as necessary, until a perfectly bright and glossy surface is obtained. Coralline limestones treated in this way exhibit all the details of animal structure.

The Yoredale Rocks and the *Millstone Grit*, which succeed, are formations of an arenaceous

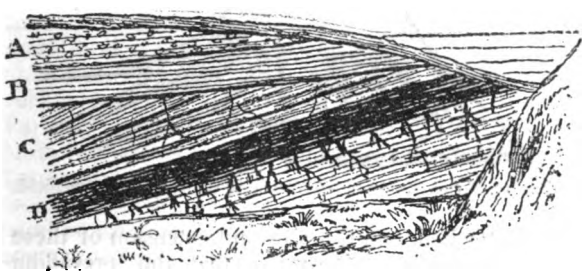

Fig. 16. Outcrop of Coal-Seam at Blackfordby, Leicestershire :—A. Breccia. B. Purple Marl, forming base of the Trias. C. Coal-Measure Shales. D. Seam of Coal, 3 feet thick. E. Under Clay, with rootlets stretching from the Coal.

type, and point to a shallowing of the Carboniferous sea. Thin beds of coal frequently occur in the Millstone Grit, showing that at times terrestrial conditions prevailed: the '*Feather-edge Seam*,' worked near Rochdale and Whaley Bridge, is a well-known Millstone Grit coal.

When we reach the *Coal Measures* proper, we find ourselves in the presence of repeated evidence of

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old land surfaces. The late Sir William Logan first ascertained in 1853, during his survey of the South Wales coal-field, that the *under clay* seen to underlie every seam was in truth the soil on which the ancient forests grew. These under clays are invariably full of Stigmariæ—long, branching rootlets shown by Mr. Binney to belong to the plant known as the Sigillaria. At Wadsley, near Sheffield, some stumps of Sigillariæ were uncovered in 1873, while digging foundations for the new Lunatic Asylum. These had the roots (*Stigmaria*)

Fig. 17. Fossil Stump of *Sigillaria* at Wadsley, near Sheffield.

still attached, and the size and extension of these proved the interesting fact that the prevailing winds were then, as now, from the west, for the roots are much larger and stronger on that side. Thanks to Mr. Sorby, these remains have been carefully preserved *in situ.*

The beds of clay, shale, sandstone, and coal which constitute our coal-fields have usually a more or less regularly basin-shaped outline. This, as Professor Hull has pointed out, is due to two distinct series of upheavals, which took place, the first at the close of the Carboniferous Epoch, along lines ranging east and west, and the second at the close of the Permian Epoch, at right angles

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to the former, or in a north and south direction. If the student will take a rough map of England, and draw lines running east and west from say Morecambe Bay to the mouth of the Tees, another from the Wash through Derby and Macclesfield to Chester, and a third from St. Bride's Bay eastwards through Coventry, he will have indicated the approximate direction of three great east and west anticlinal curves into which the strata were thrown at the close of the Carboniferous age. From the top of these curves the coal-seams, etc., would soon be denuded off. Then at a later date, at or about the end of the Permian Period, the rocks were again elevated and folded; but this time the direction of the anticlinal folds ran nearly north and south. Now was the Pennine chain upheaved, whereby the Yorkshire and Lancashire coal-fields — once continuous — were dissevered. Farther north, the Northumberland and Durham basin lost connection with that of Whitehaven and Langholm, whilst to the south similar severances took place, leaving our coal-fields as detached patches, whereas, when first formed, they probably covered the greater part of what is now England.

Formation of Coal.—The seams of coal would seem to be the result of a vegetation so rich and rank that at the present day we can scarcely find a parallel to it, unless it be in the low deltas and swamps bordering some of the great rivers of tropical regions. The plants, however, were not of high types. Gigantic club-mosses (*Lepidodendra* and *Sigillariæ*) and reeds (*Calamites*), with ferns and a few conifers, grew on extensive mud flats at or about the sea-level. Every bed of coal marks a period of repose, of fixity of level, during which generation after generation of plants grew and

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decayed, showering down their soft rain of spores upon the soil, until a mass of vegetable matter, perhaps thirty or forty feet in thickness, was formed, in a period of about one thousand years. Then subsidence followed, the land sank below the sea-level, and strata of sand, clay, etc., were deposited, on the top of which, again, perhaps other forests grew. Descending deep down into the earth, pressed upon by the weight of thousands of feet of over-

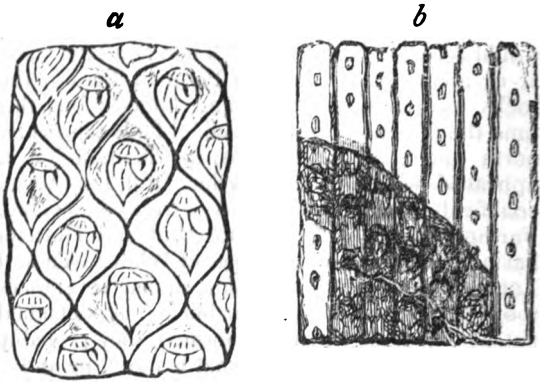

Fig. 18. Leaf-scars on stem of (*a*) *Lepidodendron*, and (*b*) *Sigillaria*, the latter with portion of bark still adhering.

lying rocks, the thirty or forty feet of vegetable matter would be compressed into a seam scarcely one yard thick. It would part with much of its gases, would blacken, and would form a mass whose origin would be hardly recognisable, were it not that here and there some fragment has been better preserved than the rest, and that under the microscope the whole is seen to be unmistakeably composed of vegetable tissues.

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In the Leicestershire coal-field the total thickness of the seams is about seventy-five feet, for which, therefore, we must allow a period of 25,000 years. But between the seams there are above two thousand feet of sandstone, clay, ironstone, etc. Now we may suppose that these materials were deposited at a more rapid rate, perhaps two feet in a century, which would give a total period of $\frac{2000 \times 100}{2} + 25{,}000 = 125{,}000$ years to produce the coal-field of Ashby-de-la-Zouch, an estimate which pretty certainly errs in being too short, but which may be useful as an approximation, and as giving an idea of the method of calculation in such cases. Elsewhere, where the strata are much thicker, of course the time required to form them would be longer; and for the South Wales coal-field, where we have a thickness of one hundred and twenty feet of coal, and twelve thousand feet of sedimentary matter, Professor Hull gives an estimate of 640,000 years.

Deep Mines.—The deepest colliery worked in Great Britain is the Rose Bridge colliery, near Wigan, where the Arley seam is won at a depth of 2445 feet. The temperature of the rock at this depth, as shown by thermometers deeply imbedded in it, is 93½° F.; the average temperature of the surface is 49° F., so that there is an increase of temperature at the rate of 1° F. for every 54 feet. The temperature of the working galleries at the bottom is, however, only 79° F., owing to the ventilating air current. According to the Report of the Royal Coal Commission of 1871, it is probable that we shall be able to work seams of coal down to a depth of 4000 feet. The Dukinfield

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colliery, also near Wigan, is second in point of depth, working the Arley mine seam at 2151 feet.

Search for Coal-Measure Fossils.—The 'pit banks' of collieries, where the rubbish is tipped, will be found generally to yield specimens of all the commoner vegetable remains, especially after the sinking of a new shaft. Colliers should be encouraged to preserve any 'curious-looking stones' they may meet with. In this way Professor L. C. Miall, curator of the Leeds Museum, has obtained from the miners of his district very fine specimens of *Labyrinthodonts*, an extinct group of Amphibians related to our frogs and toads, and named from the curiously complex structure of their teeth.

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CHAPTER VIII.

THE PERMIAN FORMATION.

WHILE the Carboniferous formation rests upon the *Old Red Sandstone*, it is also overlaid by a group of *Red rocks*, to which, therefore, in the early part of the present century, the name of *New Red Sandstone* was applied.

More exact research, however, soon showed that in these red sandstones, marls, etc., which rested upon the Coal Measures, there existed a very great and striking difference between the upper and the lower portion; and so for a time geologists spoke of the '*Lower*' and the '*Upper*' *New Red Sandstone*, until in 1841 Sir R. Murchison proposed the name of *Permian* for the *Lower New Red Sandstone*—a name which was at once generally adopted, and which has ever since been retained. The term Permian is derived from the province of Perm in Russia, where Sir Roderick found these rocks to occupy an area about double the size of France. They are also well known in Germany, and it will be an advantage to place the German and the English classification side by side.

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TABLE OF THE PERMIAN ROCKS.

GERMANY.	ENGLAND.
1. Bunter-schiefer (Variegated Shales).	1. Upper Red Sandstones and Marls.
2. Zechstein (Sequin Stone?) and Kupfer-schiefer (Copper Schist).	2. Magnesian Limestone and Marl Slate.
3. Rothe-todt-liegende (Red Dead Layers).	3. Lower Red Sandstones and Breccias.

In making these subdivisions, there is in some parts, as in Yorkshire, considerable difficulty in drawing the base line which shall separate the Permians from the reddish sandstones which form the top of the Coal Measures. In fact, in Staffordshire, Shropshire, and elsewhere, it is believed that beds which have been mapped as Permian by the Geological Survey will have, on a closer re-examination, to be relegated to the Upper Coal Measures. Nor is there less difficulty in ascertaining the precise *upper* limit. Near Nottingham, the Permian beds rest unconformably upon the Coal Measures, while they pass upwards into the Triassic beds with perfect regularity, and some geologists have consequently attempted to unite them with the latter. But, in considering the question, we must take a more general view, and, moreover, we must rely more upon palæontological than upon lithological evidence. Viewed in this way, there seems no reason to disturb the classification which assigns to the Permian the office of crowning the PALÆOZOIC SERIES of rocks; for by the life remains which it contains, it seems to form a sequel or appendix to the Carboniferous formation.

Permian Breccias.—A Breccia is a conglomerate formed of angular pebbles; and if the pebbles are

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still sharp-cornered and show little signs of wear, we judge that either (1) they have never been transported far from their parent rock, or (2) they have been so transported, but by some agent which did not subject them to any considerable amount of erosion on the way. Now, the only agent which could act in this way would be *ice*, and consequently Professor Ramsay sees in the Permian Breccias proofs of an ancient glacial period. In Cumberland, in the Vale of Eden, the rock known as brockram is a brecciated conglomerate formed of masses of carboniferous limestone. Other breccias of the same age occur in Leicestershire, Warwickshire, etc.; but the stones contained in these appear chiefly to have travelled eastward from the borders of Wales, and they are often smoothed and striated, marks strongly indicative of glacial action.

The Magnesian Limestone.—The bed of stone known most familiarly by this name occupies the coast between South Shields and Hartlepool, whence it runs southwards by Darlington, Ripon, Tadcaster, Doncaster, and Mansfield, until it dies out near Nottingham, the ancient rocks of Charnwood Forest having apparently formed part of the southern margin of the sea in which it was deposited. Along this line it varies from 100 to 300 feet in thickness, and yields at many points a good building stone. The stone used for the new Houses of Parliament came from the Bolsover quarries in Derbyshire, and the front of the Museum of Practical Geology in Jermyn Street, in which there is said to be not one single bad block, came from Anston in Notts. The Magnesian Limestone is usually of a yellowish tint, and is a true *dolomite*, *i.e.* a rock composed of nearly equal

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parts of carbonate of lime and carbonate of magnesia. It was probably deposited in an inland sea, something like the Caspian Sea of our own times, whose waters were so highly charged with salts of lime and magnesia that precipitation was constantly taking place on the sea floor, thus leading to the formation of solid beds of dolomite.

Permian Fossils.—The Marl Slate has yielded many good fish remains at East Thickley, in

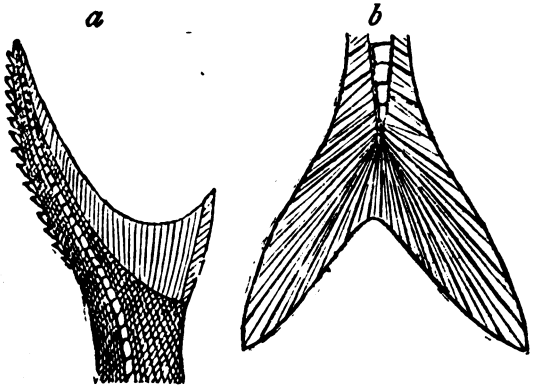

Fig. 19. (*a*) Heterocercal tail of *Pygopterus*, a Permian fish. (*b*) Homocercal tail of the Herring (*Clupea*).

Durham,—one known as *Palæoniscus comptus*, and another, *Platysomus striatus*, being most characteristic. It is worthy of note that of the forty species of fishes known in Permian rocks, all have *heterocercal* or unequally-lobed tails, the backbone being continued into the upper lobe, which is thus the larger. In this respect they agree with the other fish remains found in Palæozoic rocks, and

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resemble the shark and sturgeon of to-day. In the Triassic rocks which succeed, we find fishes with *homocercal* or equally-lobed tails, which also form the vast majority of the 9000 species which are now in existence. The shells are dwarfed and small,—a brachiopod named *Productus horridus* is perhaps best known. The plants are nearly all of Carboniferous genera, but of new species. *Walchia piniformis* may be specially noted.

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CHAPTER IX.

THE MESOZOIC OR SECONDARY PERIOD.

TRIASSIC ROCKS, *or New Red Sandstone proper.*—In entering on an examination of the Trias, the lowest division of the secondary epoch, we have to do with beds first studied and classified in Germany, and for which the German names have been retained. The word Trias is of course from the Latin *tres*, three, and indicates the fact that in Germany this formation is composed of three well-marked subdivisions, as shown in the following table :—

TRIASSIC SYSTEM.

GERMANY.	ENGLAND.
Keuper.	Keuper.
Muschelkalk.	...
Bunter-sandstein.	Bunter Sandstone.

Thus it will be seen that the Muschelkalk, a grey shelly limestone, is wanting in England.

The Bunter Sandstone.—The word *bunter* means variegated, and well expresses the bright and mottled tints of the soft reddish sandstones which form the lowest Triassic beds. They also include thick pebble beds, and generally form a light and sandy soil. In Nottinghamshire these strata form the district occupied by Sherwood Forest, which indeed owes its preservation to the fact of the poor-

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ness of the pebbly sandy soil. Nottingham itself stands on the edge of the Bunter beds, the mass of pebbly sandstone known as the Castle Rock containing numerous caves or 'rock-houses,' some of which are still used as cellars, etc.; and the Hemlock Stone, near the same town, is an interesting mass showing the junction of the Mottled Sandstone with the pebble beds. Good sections of the latter may be seen between Derby and Ashbourne, where they are used for mending roads. Every pebble bears impressed whitish marks, caused by the pressure of one stone against another; and by these we can readily distinguish the real Bunter pebble beds from later gravel or drift—the pebbles in the latter bear no such marks. The pebbles are all thoroughly well rounded, mostly of a liver-coloured or whitish quartz, and have probably been derived from pre-existing Old Red Sandstone conglomerates. The Bunter beds also occupy much of West Lancashire and Cheshire, and stretch round the South Staffordshire coal-field; they are well seen, too, around Birmingham. They yield a most abundant supply of water, but fossils they have few or none. Their total thickness is between 1000 and 2000 feet.

The Keuper.—This is the German for *copper*, and refers to the frequent presence of copper ore in beds of this age in Germany. The same mineral occurs in these beds at Alderley Edge in Cheshire. The base of the Keuper is formed of laminated micaceous sandstones, known as the 'Water stones' from the abundance of water they yield when pierced by a boring. These sandstones are four or five hundred feet thick in Lancashire and Cheshire, where they are overlaid by a great thickness of red marls, which also have towards the top another

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thinner band of sandstone — the *Upper Keuper Sandstone.*

Triassic Fossils. — Few formations are less encouraging to the young geologist than the Trias of England. Although in thickness it varies from 700 feet (in Leicestershire) to 3000 feet (in Cheshire), yet traces of life are few and far between. In the Upper Keuper Sandstone we find what appear to be tiny bivalve shells about a quarter of an inch in diameter. These once formed the

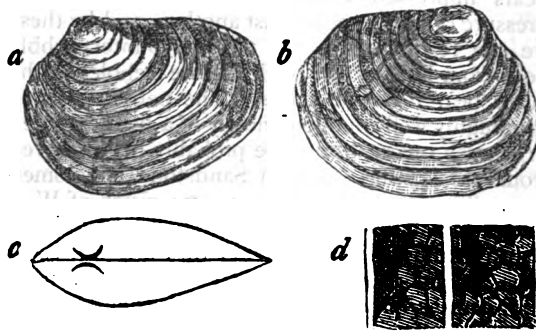

Fig. 20. *Estheria minuta.*—(*a*) Left valve. (*b*) Right valve. (*c*) Dorsal view—all magnified six diameters. (*d*) Portion of surface magnified fifty diameters.

carapace or external hard covering of a little crustacean, known as *Estheria minuta*, the living species of which inhabit fresh-water or brackish pools. But many of the sandstone slabs are covered with fossil footprints—tracks, apparently, of large and small creatures who walked or crawled over the surface of wet sand left on the shores of a tidal sea. The larger footprints are from five to eight inches in length, and so much resemble a

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human hand that the name of *Cheirotherium* (Greek *cheir*, the hand, and *therion*, a beast) was given to the creature which was supposed to have produced them. These footprints are now, however, assigned to a large amphibian, resembling in many respects the newts and frogs of to-day, but attaining a length of from five to fifteen feet. The Keuper Sandstone of Warwickshire has yielded many footprints, bones, and teeth of the *Labyrinthodon*, as Professor Owen

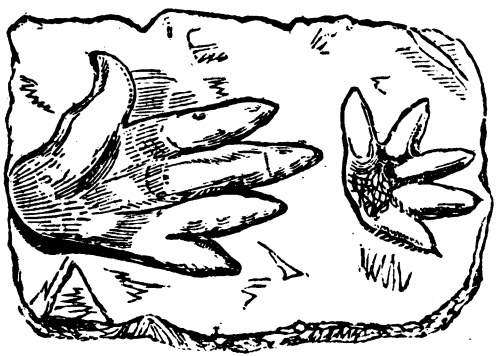

Fig. 21. Footprints of Labyrinthodon, from Storeton Hill, Cheshire.

named it, and in the Warwick Museum a fine series of these remains is displayed. When a cross section is made of one of the teeth, its microscopic structure is seen to be wonderfully complex, the layers of cement being so convoluted and twisted as to resemble the windings of a labyrinth, and hence the name *Labyrinthodon*, a creature with a labyrinth-like tooth. The Report of the British Association for 1873 (Bradford meeting) contains a masterly account of the structure of the

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Labyrinthodonts, by Professor L. C. Miall of Leeds.

Gypsum.—The Keuper beds contain the chief deposits of this mineral, whose compact white form is also known as alabaster. Crystallized gypsum is termed selenite, and the fibrous variety satin-spar. When ground up, it is called plaster of Paris, which is used for making casts, and as an ingredient of some cements. Its chemical composition is sulphate of lime ($Ca\ SO_4$). Beds of gypsum of Triassic age are well seen on either side of the Midland main line between Leicester and Syston, and it is largely worked at Chellaston and Aston in Derbyshire, at Tutbury in Staffordshire, and at Newark in Nottinghamshire.

Rock-Salt.—The Keuper or New Red Marl is also the principal repository, both in England and abroad, of rock-salt. In England salt is obtained at Nantwich, Northwich, Middlewich, etc., in Cheshire; at Droitwich and Stoke in Worcestershire; and at Shirleywich in Staffordshire. The total amount of salt obtained in 1875 was 2,316,644 tons. The beds of rock-salt appear to be of a lenticular form, and to be inter-bedded with the red marl. At Nantwich and Northwich the salt is actually mined, and appears as a rock of a dull red tint, in two beds, of which the upper is 90 feet, and the lower 150 feet in thickness. At Droitwich strong brine is pumped up from the salt-bearing strata, and is then evaporated in caldrons by heat. Owing to the removal of so much of the underlying rocks, many of the 'salt towns' have undergone considerable variations in level. The houses are all at sixes and sevens, great cracks show themselves in the walls of the buildings, and the evil effects are very visible indeed.

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But in many places where no salt now remains, we have indications of its former presence in the Keuper Marls by the numerous *pseudomorphs* of salt crystals which stud the surfaces of the grey or blue laminæ. They are cubical in form, each side of the cube being a little depressed or 'hopper-shaped.' The material of which they are formed is now hard marl, but originally they were doubtless deposited on the bottom of an inland sea whose waters were overcharged with salt, as the waters of the Dead Sea are at the present time. These salt crystals were then covered up by muddy

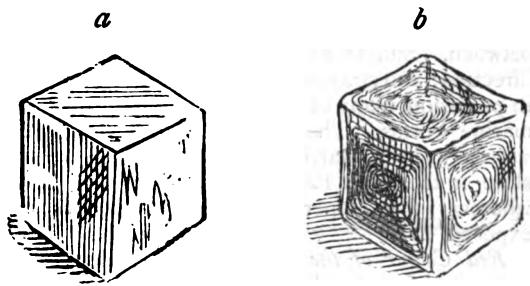

Fig. 22. (*a*) Crystal of iron pyrites, a cube with flat sides. (*b*) Crystal of salt, a cube with depressed (hopper-shaped) sides.

sediment and enclosed in the rock. At a later period water percolated through the marls, dissolving the salt and carrying it away, but every particle of salt was replaced by a particle of marly matter from the muddy water; and thus we get an exact cast or reproduction of the salt crystals in another material which does not naturally crystallize in that form, and the cast is therefore termed a *pseudomorph.* The student will obtain real salt

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crystals by allowing a saturated solution of common salt to slowly evaporate, and can then compare the crystals so obtained with these ancient forms.

Rain Pittings.—Beautiful impressions of modern raindrops may be obtained by mixing a little plaster of Paris to a stiff paste with water, and then exposing it for a few minutes to a passing shower. If the raindrops are falling vertically, we get shallow pits surrounded by a circular ring; but when they fall slantingly, the markings are oblique, and a little elevation is seen on the farther side of each depression. Precisely similar markings are seen in abundance on the Keuper Sandstones, and especially on the thin marly layers between. Suncracks, too, cross these beds in every direction; and strange rolls, lines, and furrows occur in profusion, many of them due to the burrowing of marine worms. These markings occur in profusion at the little quarries at Inkberrow in Worcestershire, in the Dane Hills near Leicester, and in fact wherever the Upper Keuper Sandstone is well exposed.

Red Colour of the Rocks.—This is due to the presence of peroxide of iron (Fe_2O_3), which is one of the most universal colouring agents of rocks. In blue or grey beds the iron is in the state of a carbonate, whilst silicate of iron gives a green tinge.

Scenery.—Thus the Trias forms a broad belt of fertile flat or undulating ground, running from the Bristol Channel to the mouth of the Tees, and spreading westwards into Cheshire and Lancashire. It constitutes the vales of York, Eden, Clwyd, Berkeley, Wrington, Taunton, etc., but here and there the hard sandstone beds give rise to picturesque escarpments or lines of hills, as the Peckforton Hills in Cheshire.

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CHAPTER X.

THE RHÆTIC OR PENARTH BEDS.

THE term *Rhætic* was first applied in Britain by Mr. Charles Moore in 1861, to certain beds which intervene between the Triassic and Liassic formations. They consist lithologically of three well-marked divisions:—

Beds.	*Average Thickness.*	
3 White Lias, ...	15	
2 Black Shales, ...	12	= 50 feet.
1 Grey Marls, ...	23	

No section exposing the junction of the Trias and Lias has yet been laid bare in the British Islands in which the Rhætic beds are not present—a sufficiently remarkable fact when we consider the slight thickness of the formation.

The name Rhætic is derived from *Rhætia*, a Roman province which was situated in the Alps between Bavaria and the plain of Lombardy. Here we find strata between 3000 and 4000 feet in thickness, of which our English rocks are the diminutive representatives. The name *Penarth* is an alternative term derived from the finest British section—that of Penarth Head, on the north side of the Bristol Channel, near Cardiff. They are also often spoken of as the *Avicula contorta beds*,

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as a shell of that name is very characteristic, especially of the black shales, which form the middle division.

Rhætic Sections.—Commencing in the south-west, the sections in the Somersetshire district have recently been fully described by Mr. H. B. Woodward in a Government Survey publication (*The Geology of East Somerset and the Bristol Coal-Fields*). At Street, Curry Rivell, St. Audries Slip, and in the various cuttings of the Great Western and Midland Railways, the various divisions are well seen. The extreme thickness attained is 150 feet at Queen Camel near Yeovil. It is the sections on the Bristol Channel, however, which are especially noteworthy and typical. At Watchet the beds are also 150 feet thick, and this is their maximum thickness; from this point, as we follow them into Yorkshire, a gradual diminution is observable. Crossing the Bristol Channel, we see, long before landing, the 'unrivalled section' which extends from Penarth Head to Lavernock Point. At the base are the strikingly coloured red marls of the Keuper; then come the *grey or 'tea-green' Rhætic marls*, 28 feet thick, surmounted by *black shales*, 24 feet thick, containing the famous 'bone-bed,' and also several bands of sandstone and grey impure limestone. Succeeding these, we find the *White Lias Series*, 18 feet thick, composed of grey and brown sandy shales, with irregular beds of limestone, thus differing lithologically from the White Lias of other sections, but identifiable by the fossils *Modiola minima*, *Lima precursor*, etc.

Passing up the Bristol Channel we find other fine Rhætic sections at Garden Cliff, Westbury on Severn, Wainlode, Aust Cliff, etc. From near Tewkesbury the Rhætic beds form a well-marked

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escarpment bounding the vale of the Severn on the east. We have traced them continuously from this point to Dunhampstead near Droitwich, where they are cut off by a fault, which limits their northward extension on this line. Here it is pleasing to note from afar the junction of the red Keuper marls with the whitish-grey Lower Rhætic beds on the freshly-ploughed sides of the escarpment, the junction being so clear and distinct as to be visible at a considerable distance.

Making a 'cast' to the eastward, we again pick up our formation at Church Lench, Hob Lench, at Cracombe, north-west of Evesham, and again at Wotton Park near Alcester, and in the railway cutting near Stratford-on-Avon. The White Lias series has been proved in the quarries at Wilmcote and Binton, and is exposed as the lowest bed in the fine section in the railway cutting at Harbury. Here it deserves its name, as it appears as a whitish earthy limestone, in strong contrast to the blue thin-bedded limestones of the Lower Lias which are seen higher up. At Eatington, Kineton, and near Rugby there are fair sections, and outlying masses occur at Wootton Warren, and at Copt Heath near Knowle. The Rev. P. B. Brodie has worked hard at the Rhætic beds of Warwickshire, and the Warwick Museum contains an excellent series of specimens illustrative of them, while its collection of Triassic organic remains is unequalled by any provincial museum.

Entering Leicestershire, we find the junction of the Lias and Trias to be so covered over with *drift*—an irregular deposit of clay, sand, and gravel of comparatively recent date—that it is impossible to trace the exact line of demarcation. Near Leicester, however, we detected an excellent exposure of the

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Rhætic beds in 1873. In the brick pits on the Spinney Hills, east of the town and within ten minutes' walk of the railway station, we see the floor of the workings to be composed of red Keuper marl. Then in the vertical 'face' of the pit we recognise the *grey marls*. With the exception of a few fish scales in the upper portion, these are thoroughly unfossiliferous; we have, however, obtained pseudomorphs of salt crystals from them, and their fissures are frequently lined with *selenite*. Very often, too, their surfaces are covered with hemispherical projections from $\frac{1}{4}$ to $\frac{1}{2}$ an inch in diameter, looking like little hillocks. These appear to be due to an efflorescence of salt at the time of their formation, the salt having since been dissolved out, and replaced by marl.

Upon these grey marls we find a representative of the *bone-bed*. This consists of about 2 inches of greyish shale, in which are embedded countless numbers of fish scales, teeth, and dorsal spines. With these are two little shells, *Axinus elongatus* and *Axinus depressus*. Every now and then a large bone of some saurian turns up, the vertebræ and ribs being of most frequent occurrence. These are highly mineralized, and traversed by cracks in all directions, so that the greatest care is necessary in removing them from the bed in which they have lain so long. Once secured, they should be immersed in a hot solution of gelatine, and the different parts united by means of isinglass dissolved in acetic acid, which forms the cement usually called *coaguline*. The Leicester bone-bed has also yielded a fragment of a tooth belonging to a fish called *Ceratodus*. Perfect teeth of the same fish are recorded in great numbers from Aust Cliff, but we believe from no other British locality.

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The *Avicula contorta shales*, which rest upon the grey marls, and of which the bone-bed may be regarded as the bottom layer, are very dark in colour, and contain much iron pyrites (Bisulphide of iron, FeS_2). In the presence of oxygen (from the air) and water, iron pyrites becomes changed into sulphate of iron, but some sulphur is liberated in the process, and the black shales are often covered with spots of sulphur of a yellowish hue; a portion is also converted into red oxide of iron (Fe_2O_3).

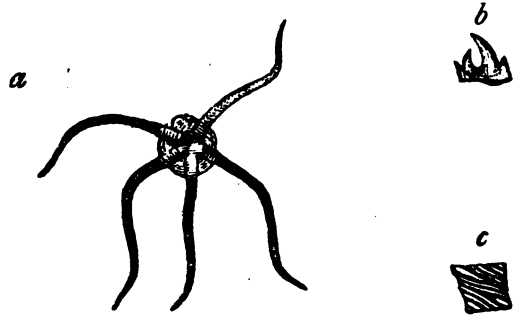

Fig. 23. (*a*) Ophiolepis Damesii. (*b*) Hybodus minor (tooth). (*c*) Gyrolepis Alberti (scale).

In consequence of this decomposition, fossils disappear from surfaces which have been exposed for some time to the atmosphere, and it is necessary to dig back several feet to secure good specimens. A further consequence of this fact is that beds might be thought destitute of fossils, if only examined at their outcrop, whereas they may really contain many, which have, however, become obliterated by a process of weathering.

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These *Avicula contorta shales* yielded at Leicester a very beautiful and delicate species of starfish, —*Ophiolepis Damesii*,—a single layer, about half an inch thick, being composed of literally thousands of the joints of this lovely echinoderm, with here

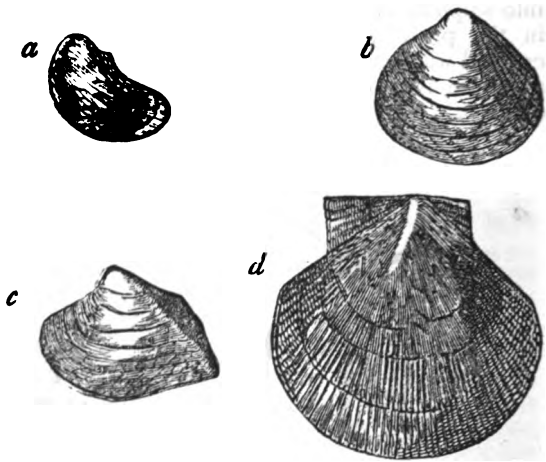

Fig. 24. (*a*) Avicula contorta. (*b*) Cardium Rhæticum. (*c*) Axinus cloacinus. (*d*) Pecten Valoniensis.

and there a perfect specimen. The characteristic shells *Avicula contorta* and *Cardium Rhæticum* are numerous. The former is immediately recognisable by the sharp twist which the shell makes to one side, being bent or 'contorted,' as it were. The Cardium is symmetrical, but has a series of fine vertical lines, running from the hinge to the edge of the shell in one corner only.

The *White Lias* is here represented by bands

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of septaria, composed of earthy limestones full of hollows resembling the cavities of a nautilus or ammonite, for which, indeed, they have been mistaken by beginners. Above these come thin limestones, not visible in the section. They are lithologically identical with the 'fire-stones' and 'guinea-bed' of Warwickshire, their surfaces being covered with the spines of a kind of sea urchin called *Hemipedina*. The septarian bands are nearly destitute of fossils.

Passing northwards we walk along an escarpment formed by the Rhætic beds and Lower Lias conjointly, until we arrive at Barrow-on-Soar. Here the junction with the Lias can be traced by means of a hard limestone band, which Mr. H. B. Woodward considers to represent the 'sun-bed' or 'jew-stone' of the south of England.

Then in Nottinghamshire we find sections at Stanton-on-the-Wolds, Elton, Barnston, etc., in the railway cuttings, and can follow them thence to Newark, where they are exposed in plaster pits near the town. Farther to the north we see the same beds in the Great Northern Railway cutting at Lea, about two miles south of Gainsborough.

From this point to the Humber the Rhætics have not been traced; in fact, the river Trent seems to run for some distance just along the line of junction. Crossing the Humber we find a drift-covered plain giving no exposures until we come to Market Weighton. From this spot Messrs. Tate and Blake have traced the beds by Pocklington and Thirsk to near Northallerton, thence curving eastwards by Stokesley and Eston to the coast near Redcar. In a pit sunk for gypsum near Eston, the following Rhætic beds were passed through:—

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	Ft.	In.
Siliceous band, ...	1	4
Dark grey shale mixed with hard bands, .	7	0
Black shales, with *Avicula contorta* and *Cardium Rhæticum*, ...	3	0
Black hard shales with gypsum, . . .	3	1
	14	5

Below the shales with gypsum were 9 feet 6 inches of blue hard marls, then 3 feet of brick-red marl, below which came 40 feet of grey marls.

Thus we do not as yet know one single section in Yorkshire which gives anything like a satisfactory exposure of the Rhætic strata.

The Rhætic Beds of Ireland.—In the north of Ireland we find ourselves upon classic ground, for here the Rhætic strata of the British Isles were first noticed by Colonel Portlock in 1843. In his Report on the Geology of Londonderry, he speaks of 'shales with *Avicula contorta*, and loose gritty marl containing *Pecten Valoniensis*.'

Scotland. — At Linksfield near Elgin, Mr. C. Moore in 1859 recognised shales and thin limestone bands. Here, below a covering of boulder clay, we get 26 feet of greenish clays and marls, with intercalated bands of stone. A 'bone-bed' contains teeth and spines of *Hybodus minor;* teeth, jaws, and scales of *Lepidotus; Sphenonchus Martini*, Agass.; teeth and vertebræ of Plesiosaurus; small univalve and bivalve shells, and plant remains. These beds rest upon cornstones belonging to the Trias, but the most remarkable fact is, that between the two formations there occurs *five feet of a red boulder clay.*

In an intensely interesting paper lately read by Professor Judd at a meeting of the Geological Society, it is stated that the Infralias (= Rhætics)

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is better developed on the north-west coasts of Scotland than is perhaps the case in any other part of the British Islands, attaining a thickness of 200 feet; and in the district of Applecross a series of estuarine beds, containing thin coal-seams, is found to be intercalated with the marine strata.

The Rhætic Sea. — The Triassic marls were shown to have probably been deposited in inland salt-lakes of great extent.

Owing to a depression of some portion or other of the encircling land, the waters of the ocean were admitted, and brought in animal life in abundance. Little sediment, however, was deposited, and so we get layers of fish scales, teeth, and spines, with bones and coprolites of saurians, forming what are called bone-beds.

The Oldest known Mammal.—In 1847 Prof. Plieninger found two minute teeth, each showing a well-defined enamelled tuberculate crown, supported by two distinct roots or fangs, in what he called a 'bone-bed in the Keuper' of Diegerloch, near Stuttgart in Germany. There is a bone-bed in the Keuper near Stuttgart; but Plieninger's specimens were without doubt obtained from the Rhætic bone-bed, which was at that time classed with the Keuper beds. His method was to carefully sift the sandy deposit and then to examine it minutely with a lens; and after scrutinizing in this way some bushels of material, the learned professor was worthily rewarded with this capital discovery of the oldest known mammal. He named it *Microlestes antiquus* (ancient little ravener).

In England, Mr. Charles Moore of Bath has displayed qualities of keenness and perseverance in the examination of Rhætic beds which must excite our warmest admiration. From fissures in

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the Carboniferous limestone at Holwell, near Frome in Somersetshire, Mr. Moore obtained in 1858 *twenty-nine teeth* belonging also to the genus *Microlestes*, but of a different species—*M. Moorei* of Owen. The deposit had evidently filled up the fissures when the rock formed the floor of the Rhætic Sea, and from three cart-loads of it which Mr. Moore removed and carefully examined, he obtained, besides the above-named mammalian remains, nine genera of reptiles, and fifteen genera of fishes. At the British Association meeting at

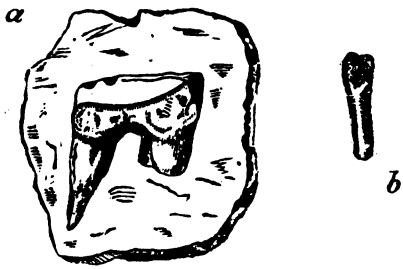

Fig. 25. (*a*) Microlestes Rhæticus, tooth magnified four diameters. (*b*) Sargodon tomicus (fish) tooth, natural size.

Bath, Mr. Moore exhibited seventy thousand teeth of *Lophodus* (a fish), and stated that the three loads of clay had probably yielded him one million specimens!

In 1864 Mr. Boyd Dawkins (then of the Geological Survey) found a small two-fanged molar in Rhætic sandstone at Watchet on the Bristol Channel. He named it *Hypsiprymnopsis*, but Owen calls it *Microlestes Rhæticus*.

Lastly, in beds assigned to the Triassic age in

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North Carolina, U.S., Prof. Emmons found two small jaw-bones, which he named *Dromatherium sylvestre* (swift-running beast of the woods). The beds in which it occurred have been variously assigned by American geologists to the Permian, Triassic, and Oolitic periods. They are now usually considered of Triassic age; but before we can definitely give to Dromatherium the rank of the very oldest known mammal, we must be certain of the contemporaneity of the American geological series with that of England, a point as to which great uncertainty must always prevail.

All these early mammals have been shown by Prof. Owen to belong to the lowest of all the mammalian orders—the *Marsupialia*, or pouched animals, now so characteristic of the continent of Australia; and their nearest living representative appears to be the little banded ant-eater (*Myrmecobius fasciatus*), which is predaceous and insectivorous, as *Microlestes* probably was.

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CHAPTER XI.

THE LIAS.

THIS term has a scientific look, but it is merely a provincialism—a corruption of the word 'layers' or 'lyers,' as applied by quarrymen to the alternation of beds of limestone and shale, which give a strikingly banded or ribbon-like appearance to the face of quarries or pits opened in its lowest division.

From the value of their industrial products and the interest of their organic remains, the Liassic rocks have attracted a large share of attention, and the following broad subdivisions of the strata have been recognised in England :—

	Feet.
Upper Lias shales and clays, . .	300
Middle Lias or marlstone, . .	40
Lower Lias clays, ...	750
Lower Lias shales and limestones, .	100

The maximum thickness is here given, but the beds vary much in this respect.

Range of the Lias.—The Lias enters England grandly, in the bold cliffs near Lyme Regis on the English Channel. Thence it pursues a steady north-north-east course by South Petherton and Stroud to Stratford-on-Avon, where it bends rather more to the east by Banbury Daventry and Rugby.

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Now turning nearly due north, it forms the stiff clay lands of East Leicestershire, between Leicester and Oakham. Here it occupies a belt of country over twenty miles in width from east to west. From Belvoir Castle it passes northwards between Lincoln and Gainsborough, its outcrop being here much narrowed by the overlap of the cretaceous strata. Crossing the Humber at Alkborough, we trace it on the east of the Rhætic beds, already described, by Market Weighton and Northallerton to Redcar; and thence it is exposed southwards along the coast, forming the lower part of the cliffs, as far as Robin Hood's Bay.

The outlying masses in Needwood Forest (Staffordshire), Whitchurch (Shropshire), and just south of Carlisle prove the former westward extension of the Lias, and we again find it over a limited area in the north-east of Ireland, in the north-east of Scotland at Dunrobin Castle on the Dornoch Firth, and in several detached patches in the Hebrides.

The Lower Lias contains near its base valuable bands of limestone, which are celebrated for their property of setting or hardening under water, hence being of great service in the construction of harbour works, etc. This is due to the presence of about 20 per cent. of silicate of alumina or pure clay. When water is added to the caustic lime obtained by burning these limestones,—that is to say, when it is 'slaked,'—a hydrated double silicate of lime and alumina is formed, which at once becomes hard and binding. There are extensive quarries at Street and Keinton in Somersetshire, Harbury, Wilmcote, Binton, Stockton, Rugby, etc. in Warwickshire, Barrow-on-Soar in Leicestershire, and at numerous other points. The same beds also yield large slabs for paving, and fair

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building stone. The surfaces of the lowest limestone bands are covered with a small oyster, *Ostrea liassica;* and just above these comes the 'insect limestone,' a fine-grained bed containing numerous elytra or wing-cases of beetles. Being small and indistinct, a very careful examination of the rock is necessary to find them.

A few feet higher we get the first British ammonite, *A. planorbis*, a smooth species, rapidly

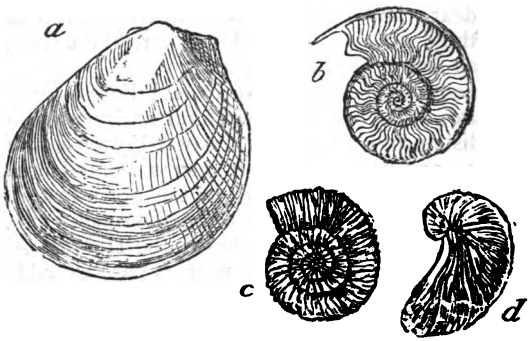

Fig. 26. (*a*) Lima gigantea. (*b*) Ammonites serpentinus. (*c*) Ammonites communis. (*d*) Gryphea incurva.

followed by other forms, which are now being described by Dr. Wright in the publications of the Palæontographical Society. A splendid bivalve shell, *Lima gigantea*, is at home on this horizon; and a little above it a curved oyster, *Gryphea incurva*, occurs in vast numbers. It is probably the descendant of *O. liassica* adapted to deeper water. Then belemnites come in, with a great number of molluscs, about a thousand species of

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the latter having already been found in the English Lias.

The Middle Lias is also known by the name of Marlstone. It includes a hard rock-bed of ferruginous limestone, which yields the famous Cleveland iron ore of North-East Yorkshire.

The Upper Lias is a thick mass of shaly clays, the 'jet rock' and 'alum shales' of Yorkshire. *Jet* is formed by the segregation (accumulation in hollows) and hardening of the bitumen with which the shales are charged. It is *not* fossil wood. The making of jet ornaments gives employment to about 1500 persons in Yorkshire; and the value of the trade in 1872 amounted to £88,000.

The manufacture of potash alum has almost deserted Whitby, formerly its chief seat. It is now chiefly made from coal shales.

The Age of Reptiles.—This term is sometimes applied to the Lias only, and sometimes to the entire Mesozoic Formation. The most characteristic Liassic reptiles are those termed *Enaliosaurians* (sea lizards), including the two great groups of Plesiosaurus (near to a lizard) and Ichthyosaurus (fish-like lizard).

The former are distinguished by their long necks; in the fine specimen in the Leicester Museum of *Plesiosaurus macrocephalus*, whose total length is 17 feet, the neck is 4 feet in length. The Ichthyosaurus may be termed the 'reptile whale' of its day. It had no visible neck, but a long powerful tail; and the eye-ball was protected by a ring of bony plates, so that the animal could dive to great depths without injuring that organ.

These saurians fed chiefly upon fishes, for we find numerous fish scales preserved in their petrified droppings, called coprolites (Greek *copros*, dung).

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Bones of these and other species of saurians are of common occurrence in the Lower Lias limestones. They are usually imbedded in a hard matrix, from which they may be removed by carefully chiselling away the stone.

The *Pterodactyl* (winged finger) represents the Pterosauria (winged lizards), reptiles which had the power of flight. The outer or fifth finger of the forearm was greatly elongated, and supported a leathery membranous expansion like the 'wing' of a bat.

Ammonite Zones.—Besides the triple division already alluded to, the Lias may be further subdivided according to the presence of certain species of ammonites which are found to be characteristic of special horizons. Thus we have—

Upper Lias	Zone of *Ammonites jurensis.*	
	,, ,,	*communis.*
	,, ,,	*serpentinus.*
Middle Lias	Zone of *Ammonites spinatus.*	
	,, ,,	*margaritatus.*
	,, ,,	*capricornus.*
	,, ,,	*Jamesoni.*
Lower Lias	Zone of *Ammonites oxynotus.*	
	,, ,,	*Bucklandi.*
	,, ,,	*angulatus.*
	,, ,,	*planorbis.*

It is not to be understood that each ammonite is confined to one single bed only, but that each species reaches a maximum development at a certain point, and that in general each species is not found out of a certain horizon of varying thickness.

Marked near its base by strata which indicate proximity to an ancient coast-line, the Liassic seabed seems then to have been gradually depressed,

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whilst deposition of sediment steadily going on almost balanced this slow sinking, so that the main mass of this formation was laid down in a somewhat shallow sea. The beds at the base of the Upper Lias, again, indicate the proximity of land; but again depression must have followed, marked by the considerable thickness of the Upper Lias clays. Under circumstances so favourable to the preservation of a complete series of the life of the period, it is not surprising that we do not meet with very sudden or striking changes in the fauna. As elsewhere, the rule holds good that the most highly organized beings have the most restricted horizontal and vertical range, and hence, also, these are most valuable in identifying any particular bed or stratum. So fresh species of *Ammonites* appear and disappear, whilst certain bivalves, as *Cardinia* and *Hippodium*, occur in the Lias only, but range widely within it, while others still pass up into the Oolitic beds.

What is a Cephalopod?—The *Cephalopoda* (head-footed) constitute the highest class of the Mollusca or shell-fish. They are named from their organs of locomotion and prehension (tentacles) being arranged round the head. They all have a shell, which may be internal or external, and which is generally chambered, *i.e.* divided by transverse partitions or septa. Living examples are the *Octopus*, *Argonaut* (paper nautilus), *Loligo* (common squid), *Sepia* (whose internal shell is the 'cuttle-bone' so often seen on our shores), *Spirula*, *Pearly Nautilus*, and *Orthoceras*. Of genera now extinct, Ammonites, Belemnites, Goniatites, and Clymenia furnish good examples. The Nautilus is the oldest of all Cephalopods, first appearing in Silurian strata. The Goniatites appear about the same time, but

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die out in the (foreign) Trias. Clymenia ranges from Devonian to Carboniferous only.

Ammonites have a many-chambered shell, the

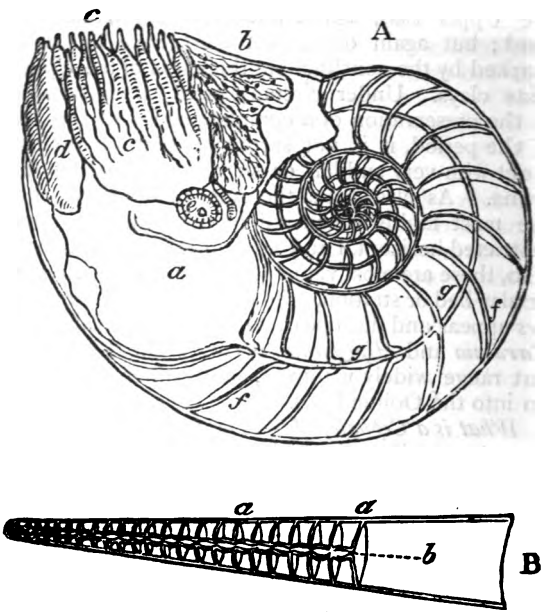

Fig. 27. A. *Nautilus pompilius* (recent), one-third of natural size. Section of shell, with the animal occupying the outer chamber: (*a*) Mantle; (*b*) Hood; (*c*) Tentacles; (*d*) Funnel; (*e*) Eye; (*f*) Septa; (*g*) Siphuncle. B. *Orthoceras* (extinct), section showing—(*a*) Septa; (*b*) Siphuncle (after Baily).

edges of the septa forming very complicated junctions (sutures) with the outer shell. The last chamber is large and was inhabited by the animal,

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which, however, kept up a communication with the other chambers by means of a tube (siphuncle) which passed round along the *outer edge* of the shell. The shell itself is a cylinder forming a flat spiral with the various turns in contact. The outer opening could be closed by an operculum or lid, long termed *Aptychus*, its real nature being made known by its being at last found in position within several specimens. The ammonite probably lived in shallow seas and fed on shell-fish, browsing head downwards on the bottom. Its range in British rocks is from the Lias to the Cretaceous inclusive. Its name is derived from the resemblance of the shell to the ram's horns found on the statues of the heathen deity Jupiter Ammon, and hence in old geologies it is usually termed *Cornu Ammonis*. Snake-stone is another obsolete name, derived from their resemblance to a coiled-up snake, the tradition being that the serpents were petrified in this manner for their misdeeds, as Scott writes in *Marmion:*

'Whitby's nuns exulting told,
. . . . . .
And how, of thousand snakes, each one
Was changed into a coil of stone
When holy Hilda prayed;
Themselves, within their holy bound,
Their stony folds had often found.'

Ammonites communis is very plentiful at Whitby, but its resemblance to a snake is incomplete for want of the necessary headpiece. The Yorkshire curiosity-dealers overcame this difficulty by carving the requisite member.

Belemnites (Greek *belemnon*, a dart) occur only in the same British formations as ammonites. The portion commonly found fossil is the *guard*, a hard,

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solid cylindrical body terminating in a cone, and roughly resembling a pointed lead-pencil. If we discover a perfect specimen, we find a hollow (*alveolus*) in the upper end, containing a chambered cone (*phragmacone*) pierced by a marginal siphuncle. Crowning all was the soft body of the animal,

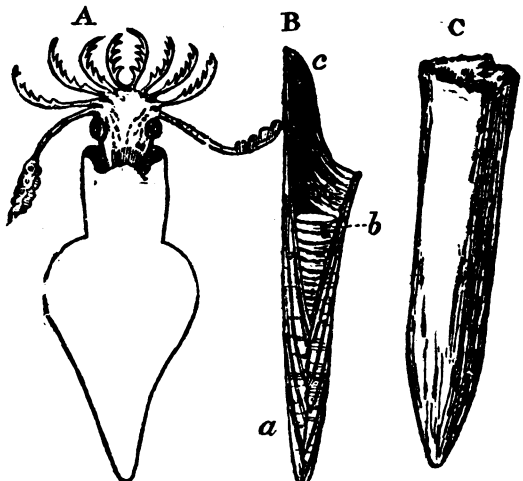

Fig. 28. A. Restoration of the animal of the Belemnite. B. Section of the complete skeleton of a Belemnite: (*a*) Guard; (*b*) Phragmacone; (*c*) Horny pen. C. *Belemnites breviformis*, from the Lias.

having tentacles armed with sharp hooks. The belemnites possessed also an ink-bag like the living Sepia, for the purpose of clouding the water when in danger of capture. The fossil ink-bag is sometimes so well preserved that its contents after dilution with water may be used for writing or

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drawing. In some parts of the country belemnites are termed 'thunder-stones,' being supposed to fall from the sky during storms. In Buckinghamshire they were formerly collected by the villagers, and considered, when pounded, as an excellent cure for rheumatism!

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CHAPTER XII.

THE OOLITE.

THE limestones of the Oolitic Period are familiar to us from their extensive use in buildings. They are usually composed of rounded grains about the size of small shot, resembling both in size and colour the roe of a fish; hence the word 'oolite' (egg-stone), from the Greek *oon*, an egg, and *lithos*, stone. Sometimes these rounded grains are as large as peas, when the stone is called a *pisolite* or *pea-grit*. Between the limestone beds there occur thick beds of clay, and thinner layers of sand. The whole Oolitic Formation forms a well-defined band, occupying the coast on the English Channel from Bridport to Portland Bill, and thence running north-east to Filey and Scarborough on the North Sea, with an average breadth of from twenty to thirty miles. Along its course the western edge of the formation is irregular, but Crewkerne, Castle Cary, Stroud, Uppingham, and Lincoln indicate it pretty fairly, whilst the eastern limit is approximately marked by the line of the chalk escarpment.

Subdivisions of the Oolitic Formation.—In the following table only the principal beds can be named. If we take the maximum thickness of each, we get a total of nearly 3000 feet. As, how-

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ever, where one bed is thick the others are usually thin, the greatest thickness at any one point is probably not one-half of this amount, or under 1500 feet.

- Upper
  - Purbeck Beds.
  - Portland Stone and Sand.
  - Kimmeridge Clay.
- Middle
  - Coral Rag.
  - Oxford Clay.
  - Kellaways Rock.
- Lower
  - Great Oolite.
    - Cornbrash.
    - Forest Marble.
    - Stonesfield Slate.
  - Fuller's Earth.
  - Inferior Oolite.
    - Lincolnshire Oolite.
    - Collyweston Slate.
    - Northampton Sand.
  - Midford Sands.

The Midford Sands are so named from a village near Bath, but they are best seen in a fine coast section east of Bridport Harbour, where they are 200 feet thick. Their fossils are a mixture of Liassic and Oolitic forms, and they have been assigned by Mr. C. Moore to the latter, and by Dr. Wright to the former formation. They are, in fact, true *passage* or transition beds. *Ammonites Jurensis* is a common fossil.

The Inferior Oolite contains some beds of excellent freestone. This term is applied to any rock which cuts or carves equally well in any direction. With sandstones and many limestones, it is necessary, when they are used for building, to lay them in the same position as they are found in the quarry, otherwise, being composed of layers, they exfoliate, *i.e.* the layers peel off one by one under the influence of the weather. In limestones of a well-defined oolitic structure, however, this precaution is un-

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necessary, since the grains are equally cemented to one another in all directions.

There are many fine sections exposed of the Inferior Oolite on the western face of the Cotswold Hills. It is here 264 feet thick, and is largely quarried at Leckhampton, Bourton, Broadway, Brockhampton, etc. Here six or more well-marked subdivisions can be traced. As we follow this formation eastward, we find it diminish to less than 10 feet near Woodstock. This thinning out, which is the case more or less with all beds, is especially noticeable in the oolitic limestones and sandstones. Every rock-bed must come to an end somewhere. The clayey strata, whose light particles were equally spread over a great expanse of sea bottom, are more persistent; but the sands and limestones deposited nearer shore are much more changeable, and they dovetail into one another in a manner which often makes it very difficult to decide what beds are contemporaneous with one another.

When we follow the Inferior Oolite northwards, we find it in the Midlands to consist of the *Northampton Sand*, from 40 to 80 feet thick, which yields a valuable ironstone. Over this comes the *Lincolnshire Oolite Limestone*, well shown in the famous quarries at Ketton and Ancaster. At its base is a thin fissile limestone, the *Collyweston Slate*, which of course is not a true slate, since it has no cleavage, but which is used for roofing. In Lincolnshire this limestone forms the well-known line of hills called the 'Cliffe,' and indeed the Inferior Oolite shows a well-marked escarpment along most of its course, the steep side, of course, facing the north-west. *Ammonites Murchisonæ*, *Pterocera Bentleyi*, and *Terebratula fimbria* will serve to characterize this stage.

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The Fuller's Earth only occurs in the south-west counties. It is a blue or yellow sandy clay, formerly much used in the manufacture of cloth, and was largely dug near Bath. The total thickness is from 120 to 150 feet.

The Great or Bath Oolite.—The limestones of this series are either shelly, when they are termed *ragstones*, or of the ordinary oolitic structure (free-

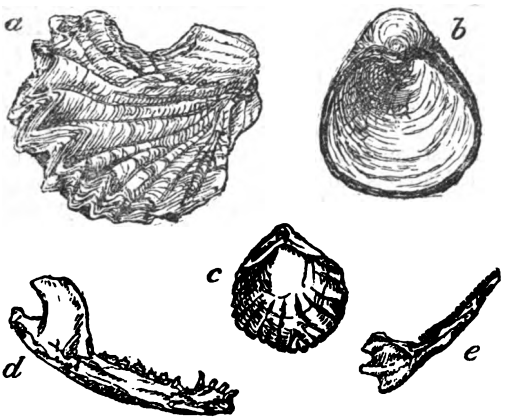

Fig. 29. (*a*) Ostrea Marshii. (*b*) Gryphea dilatata. (*c*) Terebratula fimbria. (*d*) Phascolotherium Bucklandi. (*e*) Amphitherium Prevostii.

stones). There are large quarries at Corsham, Box, Bath, Minchinhampton, etc., all in the south-west counties. The thickness there is above 100 feet. The *Stonesfield Slate* of Oxfordshire is a similar bed to the Collyweston Slate, and the two were considered contemporaneous till Professor Judd showed that the Lincolnshire Limestone and Northampton

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Sand were of *Inferior Oolite* age. At Stonesfield the lower jaws of four small species of mammals have been found; these are the oldest known, with the exception of the Rhætic *Microlestes*. They have been named *Amphitherium*, *Phascolotherium*, and *Stereognathus*. The two former were probably insect-eating marsupials, the last perhaps a small hoofed herbivorous quadruped.

The Cornbrash is a persistent irony limestone, weathering to a light, red, 'brashy' soil. Its top is marked by a stratum wholly composed of the thick rough oyster, *Ostrea Marshii*.

The Oxford Clay is a blue clay as much as 600 feet thick. It forms low flat land, very retentive of moisture, and has near its base an irregular band of calcareous sandstone, the Kellaways Rock, so named from a village in Wiltshire. *Gryphea dilatata* is a characteristic fossil.

The Coral Rag seems to have been a true 'reef.' It is quarried at Headington Hill near Oxford. Here it serves to separate the Oxford from the *Kimmeridge Clay*, which is a stiff, unctuous, shaly clay, above 600 feet thick. In the Sub-Wealden boring, however, it was found to attain the enormous thickness of 1450 feet, but nowhere at its outcrop in England does it reach half this amount. *Ostrea deltoidea* is a common fossil.

Portland Beds.—In the 'isle' of Portland, in Dorset, we find ninety feet of limestone, underlaid by about eighty feet of brown and yellow sands. Many of our public buildings, such as St. Paul's Cathedral, are built of Portland stone. The same beds are worked near Swindon and at Aylesbury, but are there much thinner.

The Purbeck Beds occur in the isle, or more properly peninsula, of Purbeck, also in Dorsetshire.

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They are mainly of fresh-water origin, deposited probably in the estuary of some great river, and serve to link on the Oolitic to the Cretaceous Formation, as the Wealden Beds, which form the base of the latter, were laid down under similar conditions. They are well seen, too, in the cliffs near Swanage, and can be traced as far north as Brill in Buckinghamshire. Their total thickness is about 330 feet. In the lower portion what are called 'Dirt Beds' can be traced. These are earthy

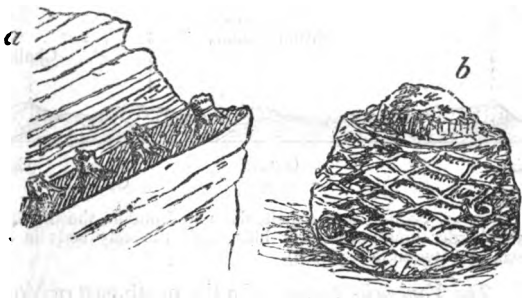

Fig. 30. (*a*) Cliff near Lulworth Cove in Dorsetshire, showing the 'Dirt Bed,' with stumps of trees. (*b*) *Mantellia megalophylla*, a cycadaceous tree from the Purbeck Dirt Bed.

beds about one foot thick, and are really the remains of old land surfaces. They contain what the quarrymen call 'birds' nests,' which are the stumps of cycadaceous trees. The 'Cinder Beds' of the central portion are thick masses of oysters (*Ostrea distorta*), and show the prevalence, for a time, of marine conditions. The upper bed contains a hard, shelly, fresh-water limestone, known as Purbeck Marble, which was formerly much used for the small clustered columns in ecclesiastical buildings.

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Hills and Vales.—It will be noticed that the Oolites consist of an alternation of hard and soft beds, of limestones and clays. Naturally the former have resisted denudation better than the latter; and so they stand out as lines of hills, while the clayey strata form the low flat vales between. This is well seen in travelling across the south of England, say from Gloucester to London.

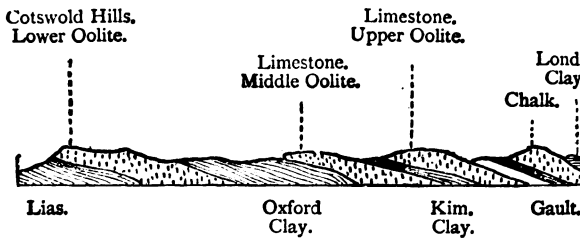

Fig. 31. Section from Cheltenham to London, showing how the harder limestones form hills, with the clay beds in the valleys between (after Lyell).

The Yorkshire Oolite.—In the north-east of Yorkshire an extensive area is formed of oolitic beds, in which sands and sandstones predominate, and which give evidence, by the occurrence in them of vegetable remains and beds of lignite, of the immediate neighbourhood of land during the time of their formation. The lower beds here are termed the 'Dogger Series,' from the occurrence of numerous rounded concretionary masses in the sands. Dogger is a local name for any rounded stone. Thin coal-seams occur, which have been worked at two or three points, but always at a loss.

The Scottish Oolite.—A few scattered patches of oolitic beds occur along the north-east coast, in Sutherlandshire and the adjoining counties, and

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similar remnants are found on the west in Skye, etc. These outliers, together with many other considerations, show a former great extension of the Oolitic Formation, which probably stretched right across England, abutting on the high land of Wales, and covering a large area in Scotland. At

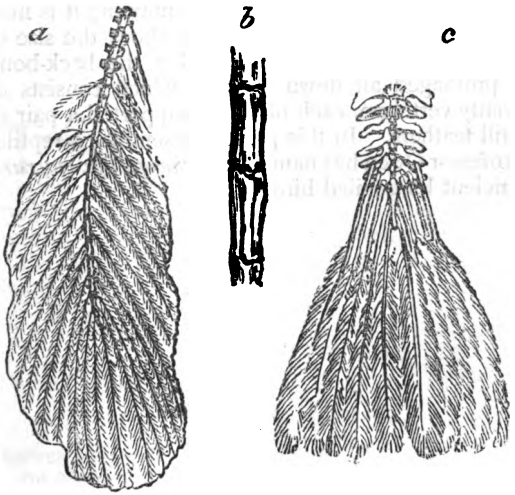

Fig. 32. (*a*) Tail of *Archæopteryx macrura*. (*b*) Vertebræ of the tail, natural size. (*c*) Tail of living Vulture for comparison with (*a*).

Brora, in Sutherlandshire, there is a well-known coal-seam, whose extreme thickness is three feet six inches. It rests on black shales full of estuarine fossils, and is surmounted by a hard sandstone called the 'roof-bed,' which is the equivalent of the Kellaways Rock of England. This oolitic coal-

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seam has been known for centuries, but the result of the workings cannot be said to be satisfactory in a pecuniary point of view.

No oolitic strata are present in Ireland.

The Oldest known Bird.—In foreign rocks, the lithographic 'slate' of Solenhofen in Bavaria (Middle Oolite) has furnished a skeleton of the oldest known bird. The slab containing it is now in the British Museum. It was about the size of a rook, and is remarkable in that the back-bone is prolonged all down the tail, which consists of twenty vertebræ, each of which supported a pair of quill feathers. In this point it resembles a reptile. Professor Owen has named it *Archæopteryx macrura* (ancient long-tailed bird).

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CHAPTER XIII.

THE CRETACEOUS FORMATION.

THE word 'cretaceous' is derived from the Latin *creta*, chalk, and is meant to express the fact that our familiar white chalk is the leading member of the set of strata which, owing to their general community, we group together under the name of the Cretaceous Formation. The leading subdivisions are—

		Feet.
UPPER CRETACEOUS,	White Chalk with Flints,	600
	White Chalk without Flints,	400
	Chalk Marl or Grey Chalk,	80
	Chloritic Marl,	20
	Upper Greensand,	200
	Gault,	100
LOWER CRETACEOUS OR NEOCOMIAN,	Lower Greensand,	500
	Wealden Beds,	2100

The Wealden.—This is the term we apply, geologically, to the strata which lie between the North and South Downs, forming part of the counties of Kent, Surrey, and Sussex. This is the old district known as 'The Weald,' from the woods which covered its hills (Anglo-Saxon *weald* or *wold*, a wooded hill). The central part of this area, from Horsham on the west, by Tunbridge Wells to Cranbrook and Hastings, is formed of sandy strata, known as the *Hastings Beds*. Crow-

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borough Beacon, 803 feet above the sea, is the culminating point of this region, which is of a hilly nature producing some fine scenery.

The Weald Clay forms a belt of low heavy land resting upon the Hastings Beds, and almost encircling them, running from Hythe by Crowhurst to Haslemere, and then east to Pevensey.

The united thickness of the Wealden Beds is above 2000 feet, and the evidence is clear that all, or very nearly all, this thick deposit was laid down as sand and mud in the estuary of a great river, which flowed probably from the north-west, draining a great continent now beneath the Atlantic. The fossils prove this. There is the great herbivorous reptile the *Iguanodon*, from 30 to 50 feet in length; fresh-water mussels, as *Unio Valdensis*; river snails, as *Paludina*, whose shells sometimes form compact hard limestones known as 'Sussex marble;' and immense numbers of little bivalved crustaceans (*Cypris spinigera*), etc. Formerly much iron was made in the Wealden from a bed of clay ironstone; but, owing to the destruction of the forests so that charcoal could no longer be obtained cheaply, and the introduction of coal elsewhere, the last furnace, that at Ashburnham, was blown out in 1828.

The Wealden Beds show a long struggle between *deposition* and *depression*, in which the latter at last triumphed. If the sea-bed at the river mouth had been stationary, the immense amount of material brought down by the stream would have formed a continually advancing delta of no great thickness; but owing to a slow movement of the earth's crust, the sea-bed here must have been gradually sinking, while at the same time the river brought down many thousands of tons of sediment annually, thus tending to neutralize the depression. At last the

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downward motion became accelerated. The coast line receded westwards, and marine conditions prevailed, under which the *Lower Greensand* was deposited. This name is due to the numerous particles of glauconite (silicate of iron), which impart a greenish tinge to the sandy beds in some localities. At this point a decided break occurs in the series of Cretaceous deposits. Of 280 species of fossils known in the Lower Cretaceous Beds, only 51 pass upwards to the Upper Cretaceous. Moreover, the Gault is usually seen to rest unconformably upon the Lower Greensand. The word *Neocomian* is used by some authors as a term for the whole of the Lower Cretaceous strata. It is derived from Neocomium, the old Latin name of Neuchatel in Switzerland, near which town strata of this age are well exposed.

Next we get a bed of stiff blue clay, the *Gault*, which name is simply a workman's term of obscure etymology. It abounds in fossils, which are often in a splendid state of preservation, the shells retaining their *test* or outer covering still resplendent with nacreous lustre. But alas! they are difficult to extract in a perfect state, and still more difficult to preserve, for as they dry they usually crumble to pieces. The remedy for this is to saturate the specimens immediately upon removal with a solution of gelatine in hot water. Folkestone is a noted collecting-ground for Gault fossils. In the Isle of Wight the Gault is termed the 'blue slipper,' for springs issue at its junction with the sandy beds above, the water being unable to pass downwards through the impervious clay. The line of junction being thus eroded, masses of the upper beds fall down the steep slopes, and in this way the famous 'Underclift' has been formed.

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The Upper Greensand is also known in Kent and Surrey by the name of Firestone or Malm Rock. In the west of England it contains much chert, which is an impure variety of flint.

All these members of the Cretaceous Series which lie below the white chalk form a narrow tract of land running across England from the coast of Dorset to Hunstanton on the Wash, and thence through Lincolnshire and Yorkshire to near Flamborough Head. They thus form the low land which lies immediately on the north-west side of the chalk escarpment. In the Wealden district they form a horse-shoe-shaped curve running from Folkestone to Farnham and Petersfield, and then east again to the coast north of Beachy Head.

Coprolite Bed.—Near Cambridge, and also in Bedfordshire, there is a bed of dark-coloured rounded lumps or nodules, very rich in phosphate of lime. These are wrongly termed *Coprolites*, and are largely worked to make artificial manure. This bed was long supposed to represent the Upper Greensand, but Mr. Jukes-Browne has shown that it is the result of the denudation of the Gault, and is to be regarded as forming the base of the *Chalk Marl*. In 1874 there were raised in the counties of Bedford and Cambridge 120,000 tons of these 'Coprolites,' valued at £312,000.

The White Chalk commences with clayey beds—the Chloritic Marl and Chalk Marl. As we follow it upwards it passes into a soft, white, earthy limestone of great purity, containing from 95 to 98 per cent. of carbonate of lime. This chalk is almost certainly a deep-sea deposit. It is an organically-formed rock—that is, it is composed of countless myriads of the microscopic shells of Foraminifera, creatures of a low degree in the animal creation,

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belonging to the class Rhizopoda of the sub-kingdom Protozoa. They are little more than specks of a jelly-like substance (*protoplasm*), but can, however, construct a shelly covering of carbonate of lime, secreted from that which exists dissolved in sea water. The microscope reveals the composition of chalk, and shows these little shells to be things of exquisite beauty. For this purpose brush a lump of chalk vigorously under water in a basin with a hard tooth-brush; now pour off the milky-looking fluid, add more water to the residue, shake, and again pour off: in a little time you will have left the more perfect shells, which, by reason of their greater weight, sink more rapidly to the bottom. Place a little of the residue on a glass slip, and examine it under a microscope with magnifying powers of from 60 to 250 diameters (1 inch and ¼ inch). Expeditions which have been sent out of late years to sound the depth and examine the nature of the bottom of the oceans, find that at depths between 5000 and 15,000 feet, the most common deposit is a greyish-white ooze composed mainly of the shells of Foraminifera, some of which (as *Globigerina bulloides*) are specifically identical with those occurring in the chalk. If this ooze were dried and compressed, it would form a rock resembling our chalk.

Strike of the Chalk.—From the white cliffs of the Dorsetshire coast we trace the chalk to the north-east by Dorchester, Salisbury Plain, Marlborough, the Ilsley Downs, and Chiltern and Gogmagog Hills, into Suffolk and Norfolk. It forms nearly the whole of the two latter counties, though, as it is here low and covered by much clay and sand (*drift*), it does not show conspicuously. In the cliff at Hunstanton a bed of red chalk is seen at

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the base. Crossing the Wash we recover the chalk in the Lincolnshire Wolds from Burgh to Louth, and thence follow it northwards across the Humber, and along the Yorkshire Wolds to where Flamborough Head looks out on the North Sea. This is the main line of strike, but in the south of England three arms branch out from it to the eastward. The first of these is incomplete, running from Dorset through the Isle of Wight; the

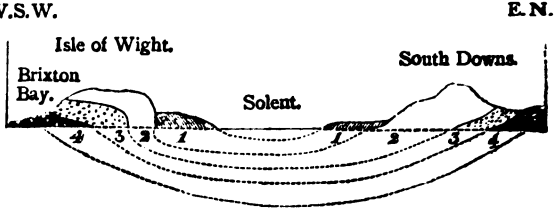

Fig. 33. Section across Sussex and the Isle of Wight:—1. Tertiary Beds; 2. The Chalk; 3. Lower Greensand; 4. Wealden Beds. The dotted lines represent the probable continuation of the strata below the surface.

second goes from Salisbury, by Winchester, to Brighton and Beachy Head (the South Downs); whilst the third runs from Andover, along the 'Hog's Back,' by Guildford, Croydon, and Rochester, to Deal and Dover (the North Downs). These eastward ribs of chalk are due to the undulations into which the formation has been thrown in the course of repeated elevations and subsidences, together with subsequent denudation. Thus in the Wealden area the chalk of the North and South Downs was once continuous all over the intervening area. When this low dome of chalk was upheaved slowly above the waters, the sea planed off the top of the dome, and 'rain and

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rivers have since completed the work, and given the surface its present configuration.

In Ireland the white chalk occurs in the north-east—in Antrim. Here it has been altered and greatly hardened by the proximity of basaltic masses—great lava-flows from volcanoes of later (Miocene) age. The Irish chalk is consequently well suited, from its superior hardness, for the cutting of microscopic sections showing Foraminifera, etc., *in situ*. On the west of Scotland, in Mull, Professor Judd has lately found Cretaceous beds which appear to be of estuarine origin.

Foreign Chalk.—In England there is a sharp break between the chalk and the succeeding strata—the Eocene beds. The Scottish beds just alluded to will doubtless supply a link, and the yellow limestone of Maestricht in Belgium, the Pisolitic limestone of the neighbourhood of Paris, and the chalk of Faxoe in Denmark, are all of later formation than the English white chalk. In the United States, however, Dr. Hayden's researches have shown in the country along the eastern side of the Rocky Mountains thick beds of marl, sandstone, and lignite, where Cretaceous fossils such as ammonites and belemnites are found associated with Tertiary shells, thus affording an instance of passage beds between the great Mesozoic and Cainozoic Periods, which, almost everywhere else, are so sharply divided.

First Appearance of Angiosperms.—Angiosperms include all trees, shrubs, and flowering plants which have their seeds enclosed in seed-vessels. Pines (Conifers) and Cycads have their seeds naked or unprotected by any seed-vessel, and are therefore termed *gymnosperms*. Now at Aix-la-Chapelle in Prussia, and in the United States, we have

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Cretaceous strata which were deposited under estuarine conditions. From them many leaves and other vegetable remains have been obtained, which are the earliest known remains of Angiosperms. They include the oak (*quercus*), beech (*fagus*), fig (*ficus*), and many other of our forest trees, and give the earliest indication of a vegetation resembling that of the present day.

Scenery.—To the geologist the chalk hills are easily recognisable by their smooth, swelling, rounded outlines, covered with a short, dense herbage, which affords good pasturage for sheep and famous training-grounds for horses. The valleys on the slopes are usually dry, owing to the fact that chalk is a porous rock, and permits the rain to sink in, and then slowly to percolate through the mass, which thus forms both a reservoir and a filter of the most superior kind.

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CHAPTER XIV.

THE CRETACEOUS FORMATION—*continued.*

ARTESIAN WELLS.—The water which falls on the North Downs or on the Chiltern Hills, and which is absorbed by the rock, percolates slowly downwards until it reaches the level of permanent saturation, or the line below which the rock is fully charged with water. Now the chalk of these two lines of hills is continuous underneath newer strata. The beds of the North Downs dip to the north, and those of the Chiltern Hills dip to the south, so that a well a few hundred feet deep anywhere near London pierces the chalk. Now the hill-tops on which the rain falls are much higher than London, and as water will always rise to the height from which it fell, it follows that when they tap the water in the chalk under London, it rises up the well-hole, and even bursts out in a jet above the surface. Wells in which the water rises in such a manner are termed Artesian wells, from the fact that these principles are said to have been first applied in the province of Artois in France. It is necessary that some impervious bed should *underlie* the water-bearing stratum, to prevent the downward passage of the water, and in the case of the chalk this office is performed by the stiff clay termed the Gault. The fountains in Trafalgar

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Square are supplied with this water by a well 383 feet deep, which enters the chalk at a depth of 248 feet.

In a Chalk Quarry.—Let us strap on our hammers and collecting-bags and resolve to make personal acquaintance with the rock we are studying. With London geologists the famous pit at Charlton, near Woolwich, is easy of access; but we cannot walk any distance along the 'Downs,' whether they be those encompasing the Weald, or in the Isle of Wight, or elsewhere, without seeing a dazzling white face of rock which can belong to no other British stratum than the well-known 'white chalk.' We need not fear wetting our feet; the absorptive powers of the chalk are great, and in a few hours after the heaviest rains the bottom of the pit is dry. Picking up a lump of the rock near the entrance, we remark that it is singularly homogeneous. It shows little or no tendency to split in one direction rather than another. How, then, are we to detect the dip? Looking at the 'face,' we see it crossed by irregular black lines which we at once recognise to be flints. As we face them, they appear to be horizontal; but looking at the *sides* of the quarry, we see that these lines slant or dip due north at about five degrees. This will be a lesson to us not to accept the apparent horizontality of a bed without further evidence, if we can only see it from one point of view. The flints, then, indicate the direction and amount of dip. Fossils may be plentiful, and yet not easy to find without some experience in the search. The outer covering or shell is usually well preserved; but, as it is of a light, creamy colour, it harmonizes well with the colour of the rock, and needs close looking for. Walk slowly round the sides, scrutinizing the wall of rock carefully. Here

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is a rounded mass projecting from the rock, and about two inches in diameter; it is a sea-urchin, and on carefully dislodging it with the cold chisel and hammer it proves to be *Ananchytes ovatus*, one of the most common species. This oval shell with unequal valves must be a brachiopod; yes, it is *Terebratula globosa*. But here are the quarrymen coming back from dinner, and an appeal to them causes the production from jacket pockets, and various occult hiding-places among the rocks, of a whole host of specimens, of which we select the best; and, carefully numbering them and wrapping each in paper, we commit them to our wallet, not forgetting to suitably reward the finders, and to admonish them to preserve in the future everything 'curious' that comes under their notice. Specimens secured in this way are jocularly assigned to the agency of the 'silver hammer.'

In one corner of the pit the flint layers are not continuous. On one side of a slanting line they are four feet lower than on the other, and we can distinctly trace the fissure, or crack, or dislocation, or *fault*. Borrowing a pick, we break down large lumps on either side, and, just at the junction with the fault, we find them smoothed and polished, and traversed by striations or fine lines, which run parallel to the fault. These are termed *slickensides*, and are evidently due to the rubbing of one face of rock against the other. We note that the beds have dropped down on the side to which the line of the fault inclines; this is what miners mean when they say 'the fault *hades* to the downthrow,' and this rule is almost universally true. Still there are exceptions, and these are called 'reversed faults.'

The top of the chalk pit has a thin covering of

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reddish loam, and at some points we see this extends down in pipes for 8 or 10 feet. These pipes have been formed by the agency of water percolating through the loam and slowly dissolving the chalk, the sand etc. sinking down to fill its place.

Flint.—What is it, and how came it in the chalk? An analysis tells us that it is composed of silex or silica, having the composition $Si\ O_2$ (one atom of the element silicon, and two atoms of the element oxygen), which is identical with that of quartz, glass, and sand.

Now sea water contains this silica in solution, *i.e.* dissolved in it, just as it contains carbonate of lime, chloride of sodium (common salt), and many other minerals. The majority of the creatures living in the sea and having a hard crust, or covering, or shell, construct their shell out of carbonate of lime; but some, as the microscopic animals known as *Polycystineæ*, and the equally minute plants called *Diatoms*, form their hard parts of silica. At the present day the North Atlantic soundings show that where cold currents from the Arctic Ocean prevail, there the sea-bed is occupied by these siliceous organisms, and they were probably one source of the chalk flints.

Many flints, when treated with acid, or sliced and examined microscopically, reveal a spongeous structure; and, according to the late Dr. Bowerbank, all flints were formed by the deposit of siliceous matter, previously held in solution in the waters of the ocean, upon and around decaying sponges. Indeed, most flints can be shown either to have an organic structure, or to have accumulated round some shell or other organic nucleus. Mr. M. H. Johnson has surmised that the silica of the

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sea water replaced the *carbon* of the decaying organic substance atom by atom, so that at last we have a complete reproduction or pseudomorph of the original in silica. Professor Rupert Jones has shown that silica often replaces carbonate of lime, more especially when the latter is in an amorphous or non-crystalline state. The sheets of flint found filling cracks or fissures in the chalk were probably deposited from water charged with silica percolating through the rock.

Economic Uses of Chalk.—It is largely got for burning into lime, which is then used for building purposes, or to spread over the land. At Gray's in Essex, and Kintbury in Berkshire, the chalk is quarried for the manufacture of *whiting*. It is ground up with water and then allowed to settle in tanks, the sediment being collected, made into cakes, and dried in the open air. It has also been used for building, and is not ill adapted for interior work. The flints are used for road metal, and also in the manufacture of glass and porcelain.

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CHAPTER XV.

THE CAINOZOIC PERIOD.

THE *Cainozoic Period*, from *kainos*, recent, and *zoe*, life, includes all the rocks which have been formed since the chalk. According to the old nomenclature, which called the Palæozoic strata *Primary*, and the Mesozoic *Secondary*, the Cainozoic Period would include the *Tertiary* (third) and *Quaternary* (fourth) strata. These latter terms, however, though they are still used in a familiar way, are open to many objections, for the line of division between them is a very shaky and doubtful one. We may here allude to another word, *Neozoic* (*neos*, new, and *zoe*, life), which includes all the strata formed since the Permian, *i.e.* both the Mesozoic and Cainozoic Periods. It was proposed by Edward Forbes, on the ground that the 'prophetic types'[1] of the life which now exists appeared early in the Mesozoic Period.

The following table shows clearly the relationship of these principal names of the stratified rocks :—

Neozoic,	Cainozoic, . .	Quaternary. / Tertiary.
	Mesozoic, . . .	Secondary.
Palæozoic,	Palæozoic, . . .	Primary.

[1] Such as the first mammal (*Microlestes*), the first fishes with homocercal tails, etc.

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Before beginning to consider the Cainozoic series in detail, it will be useful to give a general view of their subdivisions in the form of another table.

CAINOZOIC PERIOD.

Quaternary or Post-Tertiary,	Recent, ...	Post-Glacial Deposits.
	Post-Pliocene or Pleistocene,	Glacial Beds.
Tertiary, .	Pliocene, . .	Norwich Crag.
		Red Crag.
		Coralline Crag.
	Miocene, . . .	Bovey Tracey Beds.
		Hempstead Beds.
	Eocene, . . .	Bembridge Beds.
		Osborne Beds.
		Headon Beds.
		Bagshot Beds.
		London Clay.
		Oldhaven Beds.
		Woolwich and Reading Beds.
		Thanet Sands.

Tertiary Epoch.—The three divisions of this epoch—the Eocene, Miocene, and Pliocene—were so named by Sir Charles Lyell in 1833, according to the proportion of shells of still living species which they contained. In the Eocene (*eos*, dawn, *kainos*, recent) strata, about $3\frac{1}{2}$ per cent. of the Mollusca were found to be identical with living species; in the Miocene (*meion*, less, *kainos*, recent), about 17 per cent.; and in the Pliocene (*pleion*, more, *kainos*, recent), from 35 to 95 per cent. As a proof of the great break or interval which occurred, in England at all events, between the Chalk and the Eocene beds, we may state that no species of animal of any kind is known to have survived from Cretaceous to Eocene or later times. There is a doubtful exception, however, in favour of

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one brachiopod shell, *Terebratula caput serpentis*, which now inhabits the Atlantic, and which cannot be distinguished from *Terebratula striata*, a well-known chalk fossil. Some living Foraminifera, too, seem identical with chalk forms, but they are too low in the scale of life to yield evidence of much value; inhabiting the deep-sea bottom, the surrounding conditions change scarcely at all, so the forams, too, remain unaltered.

THE EOCENE FORMATION.—If we want to examine strata of this age, we must travel to the south or south-east of England. Here the Eocene Beds lie in two hollows, or undulations, or synclinals of the chalk, known as the London Basin and the Hampshire Basin respectively.

The lowest beds Professor Prestwich has named the *Thanet Sands*, because they are well exhibited in the Isle of Thanet, where they are about 60 feet thick. Their base is marked by a layer of green-coated flints resting upon the chalk. This layer is called by the workmen the 'Bullhead Bed.' It is supposed to have been formed since the deposition of the Tertiary strata by the dissolution of the chalk by means of carbonated water percolating along the line of junction. The carbonate of lime (chalk) would be carried away in solution by the water, but the flints would be unaffected. Their colour is due to silicate of iron. We can trace the Thanet Beds as far west as Windsor, but they do not occur in the Hampshire Basin. They are very unfossiliferous (except in East Kent); *Cyprina Morrisii* is a characteristic shell.

The Woolwich and Reading Beds were formerly called the *Plastic Clay*. They consist of alternations of clays and sands of many colours, with beds of rolled flints; in the London Basin they do not ex-

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ceed 90 feet, but in the Isle of Wight are as much as 163 feet in thickness. In the former area we can trace them from Sandwich in Kent, westwards to near Hungerford, and thence north-east by Watford and Bishop's Stortford to Ipswich. They mark out, in fact, the limits of the 'London Basin,' and show it to be incomplete, as on the east it is terminated abruptly by the German Ocean. Similarly in the Hampshire Basin we find the Woolwich and Reading Beds on the north side running from Arundel and Chichester to the north of Romsey, and through Cranborne to the Dorset coast east of Weymouth. Passing under the Solent, the strata rise again in the Isle of Wight, and are finely exposed, resting upon the chalk, in Alum Bay on the west and in Whitecliff Bay on the east of the island. They have a double name, because at Woolwich and other places they are fossiliferous, containing such shells as *Ostrea bellovacina*, *Melania inquinata*, etc.; whilst at Reading and elsewhere they are without fossils. These beds with the Thanet Sands and Chalk are finely exposed in the great pit near Charlton station (Woolwich), where they are worked to furnish ballast for ships. They are also well exposed at Loam Pit Hill, near Lewisham.

The Oldhaven Beds were first recognised as a separate division by Mr. Whitaker in 1866. They are only some 30 feet thick, and include the beds of rolled flints which form Blackheath, Plumstead Common, etc. They are named from Oldhaven Gap on the Kentish coast, where they are well exposed. Sometimes the pebbles are cemented together, when they form a pudding-stone or conglomerate.

The London Clay forms the greater part of the

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county of Middlesex, the south and east of Essex, etc. It is a stiff brown or bluish clay, in which occur at intervals layers of *septaria*, which are rounded nodules of impure carbonate of lime. The word septarium is from the Latin *septum*, a division, and these nodules are traversed by cracks filled with spar (crystallized carbonate of lime); they are commonly called turtle stones, or (the smaller ones) beetle stones. At the surface the London Clay is always brown, but blue when dug at any depth. This is owing to the fact that the carbonate of iron, which tinges the lower beds blue, changes to the brown peroxide of iron when exposed to the action of the atmosphere. Where the London Clay rests upon the Reading Beds, the junction is marked by green and yellow sands containing rounded flint pebbles. This is called the *basement bed*, and is only a few feet thick; it contains numerous fossils, as fish teeth, shells, etc. The upper part of the London Clay is rather sandy, and good bricks are made from it. In thickness it increases as we follow it eastwards, so that in South Essex it is 480 feet thick. It is exposed in numerous brickyards, but fossils are not to be easily found. They seem to occur in bands, certain levels being very productive, whilst above and below fossils are wanting. At Highgate and Hampstead, north of London, many beautiful specimens have been found. These fossils indicate a rather warm climate, and show that the beds were probably deposited in the sea, but not far from the mouth of a great river. Sheppey is a noted locality for fossils, and here fruits of palms (*Nipadites ellipticus*, for instance) are common. Turtles, too, are not uncommon, with such shells as *Nautilus imperialis*, *Pectunculus brevirostrum*,

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etc., and fossil wood full of holes, due to the boring marine bivalve, the *Teredo.* At Sheppey, too, the remains of a remarkable bird, the *Odontopteryx toliapicus* (toothed bird of Sheppey), have been found, and described by Professor Owen as web-footed, and having jaws provided with bony projections which served to aid in securing its prey.

The Bagshot Beds form the well-known heath of that name in Berkshire. Here they are about 100 feet thick, sandy, and unfossiliferous. On Harrow Hill, Hampstead Heath, Langdon Hill in Essex, etc., there are outlying patches of these beds. Here even the tyro can readily trace the boundary of the strata, as the water issues at the junction with the impervious clays beneath, forming springs and rendering the lower ground wet and boggy. In Hampshire the Bagshot Beds occupy the New Forest district, and much of the south of the county. At Bracklesham Bay in Sussex they are clayey and highly fossiliferous, *Cardita planicosta*, *Cerithium giganteum*, and *Nummulites lævigata* abounding.

In the Isle of Wight they form the brilliantly-coloured sands of Alum Bay. Here, and near Bournemouth in Hants, the seams of clay are rich in fossil leaves, which have been diligently collected and studied by Mr. J. S. Gardner.

The Upper Eocene Beds.—The Headon, Osborne, and Bembridge Series are almost confined to the Isle of Wight. They are chiefly of fresh-water or estuarine origin. *Helix labyrinthica*, a land snail, found fossil in the Headon Beds, is now found living in the United States. The fresh-water limestones of the Bembridge Beds are largely worked at Binsted, and here occur the earliest remains of *large mammals* which have yet been found. The

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Palæotherium may be specially mentioned, of which one species (*Palæotherium magnum*) equalled a horse in size. These animals belonged to the Ungulata or hoofed quadrupeds, and their remains were first detected in the gypseous strata (Eocene) of the neighbourhood of Paris, where

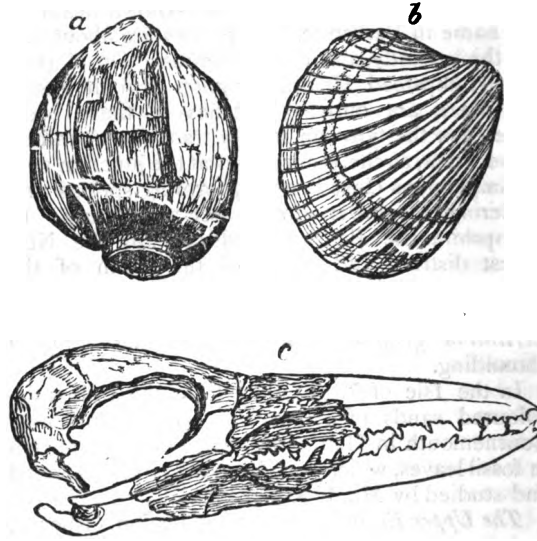

Fig. 34. (*a*) Nipadites ellipticus. (*b*) Cardita planicosta. (*c*) Odontopteryx toliapicus.

they formed the subject of Cuvier's earliest researches.

Looking abroad, we find that Paris, like London, stands on a basin of Eocene strata, whilst in the United States they are grandly developed, the

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marine strata forming a band along the Atlantic coast; while fresh-water beds of Eocene age are found on and near the Rocky Mountain range, where, as we have already pointed out, they pass downwards with scarcely a break into the Cretaceous Formation.

Nummulitic Limestone.—Nummulites are foraminifers of the largest size, the largest species being more than an inch in diameter. They are disc-shaped, resembling a piece of money, whence their name (*nummus*, a coin). Their remains form limestone beds of great thickness, which can be traced along the greater part of the mountain axis of the Old World, reaching up to a height of 10,000 feet in the Alps, and 16,500 feet in the Himalayas, thus proving the comparative youth of these mountain ranges, since the limestone must have been formed below the level of the sea. This formation is assigned to the middle of the Eocene Period. The Pyramids of Egypt are built of nummulitic limestone, and we find that the old historian Herodotus noticed the fossils, but, alas for his reputation as a naturalist, he thought they were beans!

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CHAPTER XVI.

THE MIOCENE FORMATION.

STRATA of this age are hardly represented in the British Isles, which were probably dry land at that time.

The Bovey Tracey Beds occur near the village of that name between Exeter and Teignmouth. They were explored by Mr. Pengelly in 1857 (the requisite funds being provided by the Baroness Burdett-Coutts), and the plant remains obtained were submitted to the great Swiss botanist, Professor Oswald Heer. Living plants are classed chiefly according to the characters of the flower and fruit; but these seldom occur in a fossil state, the leaves being the part mostly found. If we hold a leaf up to the light, we shall see that it is crossed by numerous lines or veins, and the arrangement of these is termed the *venation*. Now Professor Heer has made a special study of the venation of living plants, and has been able by this aid to properly describe and classify the fossil ones. He found the commonest Bovey leaf to be that of a great conifer, *Sequoia Couttsiæ*, which seems closely allied to the famous *Wellingtonia gigantea* of California. Remains of the cinnamon, evergreen oak, fig, vine, etc., were also common. The matted remains of the plants formed thick

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beds of lignite (wood-coal), which were formerly worked.

Thick clay beds are worked in the neighbourhood at Newton Abbot and Kingsteignton, and the deposit has a total thickness of about 300 feet. These Bovey Beds are probably an old lake deposit.

At Hempstead Cliff, near Yarmouth, in the Isle of Wight, are seen about 160 feet of marly beds of fresh-water origin, capped by about 10 feet of marine clays containing the shells *Corbula pisum* and *Voluta Rathieri.* These beds some geologists class with the Upper Eocene; but as they contain four species of plants also found at Bovey, we shall regard them as of Miocene age.

Leaf Beds of Mull.—In 1851 the Duke of Argyll found thin earthy beds full of leaves in the island of Mull, one of the Hebrides or Western Isles. They were interstratified with volcanic ashes, and the leaves belonged to species characteristic of Miocene deposits. Similar beds have since been found in the basaltic region of Antrim and the Giant's Causeway, in the north-east of Ireland.

In foreign countries we note as of Miocene age the *Faluns* of the valley of the Loire, the *Molasse* (soft greenish sandstone) of Switzerland, and the strata of the *Siwalik Hills*, a low range at the southern foot of the Himalayas. Most remarkable, too, is the occurrence of Miocene beds full of such plants as the beech, oak, maple, magnolia, etc., in Greenland and Spitzbergen, within twelve degrees of the pole, where the ground is now covered with almost perpetual ice and snow.

Among the life of the Miocene age we may note the first appearance of the great mammalian group

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known as *Proboscideans*, which includes the *Dinotherium*, the *Mastodon*, and the *Elephant*. Of these the two former are now extinct, but their bones have been found in the Siwalik Hills and in Europe. Of the genus *Elephas*, which still exists, no traces have as yet been found in Miocene rocks.

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CHAPTER XVII.

THE PLIOCENE FORMATION.

IN England, beds of Pliocene age are restricted to the eastern counties, and even there are of limited extent and thickness. They are known as the *Crag*, from the Celtic word *creggan*, a shell, because they are chiefly shelly sands, so rich in carbonate of lime as to be useful in agriculture. There are not many sections in which the various subdivisions can be seen resting upon each other, and hence we are driven to rely more upon the palæontological evidence than upon that furnished by superposition as to their relative age.

The Coralline Crag.—This is also known as the White Crag, the Suffolk Crag, or the Bryozoan Crag. It is about 50 feet thick, and has a coprolite bed at its base. It is exposed near Woodbridge, Aldborough, Orford, etc. The fossils, whose abundance led to its being termed the 'Coralline Crag,' now turn out to be not corals but Bryozoa, which belong to a separate sub-kingdom—the *Molluscoida*.

The Red Crag.—This is so named from the dark-red tint of its sands, which are coloured by peroxide of iron, even the fossils being deeply stained. At Walton-on-the-Naze, in Essex, the Red Crag rests on the London Clay; but at Tattingstone, near Ipswich, and again near Aldborough, it is distinctly seen

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to be underlain by the Coralline Crag. It is also well shown at Sutton, Ramsholt, and Bawdsey, all in Suffolk, and averages about 25 feet in thickness. At its base is a bed of brown phosphatic nodules, wrongly called coprolites, first noted by the late Professor Henslow. These are extracted for the manufacture of artificial manures; they contain from 40 to 60 per cent. of phosphate of lime. *Trophon antiquum*, *Pecten opercularis*, and *Purpura tetragona* may be noted as Red Crag fossils; but many fossils found in these beds are *derivative*, *i.e.* washed out of some older formation, and must not be taken as showing that the animals to which they belonged lived while the Red Crag was being deposited. Such derived specimens may usually be recognised by their worn and rolled appearance. In some places the Red Crag is seen to be overlaid by certain unfossiliferous sands, which different observers have assigned to different formations. Mr. Whittaker, however, has lately shown that these unfossiliferous sands are part of the Red Crag itself, and that the absence of fossils, and the apparently irregular junction with the Red Crag beneath, are due to the action of carbonated water, which has dissolved the shells and altered the appearance of the upper strata.

The Norwich Crag is about 30 feet thick. It occurs near Norwich, as at Bramerton and Thorpe on the banks of the Yare. Here it rests upon the chalk, and is overlaid by Glacial beds. It has also been called the 'Fluvio-marine Crag,' and the 'Mammaliferous Crag.' At its base is a stratum full of large flints, called the Stone Bed, which contains many mammalian remains, including *Mastodon arvernensis*, *Elephas meridionalis*, etc.

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The Chillesford and Aldeby Beds are named after two villages in Suffolk. They consist of sands and clays about 20 feet thick. Two-thirds of the shells found in them belong to species which now only inhabit northern seas.

On the southern shores of Lough Neagh, in the north of Ireland, there are certain clay beds, 500 feet thick, which Professor Hull considers to be of Pliocene age. In foreign countries strata of this period are found near Antwerp, and in Italy (where they form the Sub-Apennine Hills), Sicily, the south of Russia, and in Carolina and Missouri, U.S.

Thus in the Crag deposits we have evidence of a gradual cooling of the climate of this country from the time of the Coralline Crag, for in the latter the majority of the molluscs are such as now inhabit warm seas like the Mediterranean; while, as we have pointed out above, in the upper beds the shells have a northern facies. Moreover, large angular stones often occur in the Red and Norwich Crags, which have evidently travelled some distance, the agent of conveyance being probably floating ice.

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CHAPTER XVIII.

THE QUATERNARY PERIOD.

WE now enter upon that division of Cainozoic time when all the Mollusca are of living species. This is the Quaternary Period. We divide it into two sections, Pleistocene and Recent. In the older of these, some of the mammalian remains belong to extinct species—this is the Pleistocene Formation; in the newer or Recent beds, all the fossils are of existing species, *i.e.* there are still creatures living which cannot be distinguished from them.

THE PLEISTOCENE FORMATION.—This word is derived from *pleistos*, most, and *kainos*, new or recent; it is also known as the Post-Pliocene Formation. In studying it, we shall find ourselves chiefly engaged with problems concerning the last Glacial Period; and, accordingly, we may subdivide it with reference to this great ice age as follows:—

Upper Glacial Deposits.
Middle Glacial Deposits.
Lower Glacial Deposits.
Pre-Glacial Deposits.

The most complete series of these glacial beds is to be seen along the east coast of England, between Yorkshire and the mouth of the Thames; and here they have been carefully studied and

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described by Mr. Searles V. Wood, jun. The most complete account, however, of the glacial beds generally, is contained in Mr. James Geikie's excellent book, *The Great Ice Age.*

Pre-Glacial Beds.—On the Norfolk coast at Cromer, and extending for a considerable distance both to the north and south between Runton and Kessingland, there occurs the well-known *Forest Bed.* Numerous stumps of trees are seen on the beach at low water, although they are too often obscured by the sand, shingle, etc., the result of the washing away of the cliffs. Cones of the Scotch fir and spruce are common, with the bones of many mammals, such as *Elephas antiquus*, *Hippopotamus*, *Rhinoceros*, etc. It is now generally considered, however, that these bones have been derived from the destruction of some member of the Crag Series, and that the animals to which they belonged did not live here while the trees of the 'Forest Bed' were growing.

The *Bure Valley Beds* are orange-coloured pebbly sands, which occur in the east of Norfolk. Mr. Wood considers them to be the commencement of the whole Glacial Series, for they rest *unconformably* upon the Chillesford Beds; and in them the shell *Tellina Balthica* makes its first appearance, this mollusc being highly characteristic of the truly glacial beds of the British Isles.

Lower Glacial Beds.—Resting upon the pre-glacial deposits, we find at Cromer and in the cliffs of the Norfolk coast a very different series of beds, about 200 feet thick, which have evidently been formed under very different conditions. First comes the *Cromer Till*, a greyish clay containing rounded and scratched stones, such as chalk, flint, blue basalt, pink granite, etc. Above this we find

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the *Contorted Drift*, a yellowish, loamy, and gravelly deposit, remarkable for the way in which the layers have been bent or 'contorted' by some force acting since their deposition. In this, immense masses of chalk are embedded, some of which measure hundreds of feet in length. A few marine shells occur, among which *Tellina balthica* is recognisable. It is very difficult indeed to say whether there are in any part of the British Isles glacial beds of the same age as this Lower Glacial Series of Norfolk. Very probably there are none so old, at all events among those which have yet been studied; for in the north of England and in Scotland, the land was occupied, not once but several times, by an ice sheet, and the earliest deposits were thus there obliterated.

Middle Inter-Glacial Beds.—These are beds of sand and gravel, from 15 to 70 feet thick, which occur in Leicestershire and Norfolk, and run south from thence to the north side of the valley of the Thames. They are usually false-bedded, and often streaked with black carbonaceous markings. Fossils are scarce, but near Yarmouth shells have been found, some of which belong to extinct Crag species, as *Astarte Omalii*, etc., and others which indicate a mild climate. These beds seem to attain an altitude not exceeding 380 feet. Near Brandon in Suffolk, there are some beds of brick earth of this age, in which Mr. S. J. B. Skertchley has found flint implements, undoubtedly the work of man, and which are, so far, the earliest indications of the existence of human beings on the earth.

Upper Glacial Beds.—Overlying the gravelly deposits just described, we find in the east and east midland counties of England a stiff clay, usually

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of a bluish tint, and full of fragments of chalk of all sizes, from that of a pin's head upwards. This is the *Great Chalky Boulder Clay*. It contains flints, sandstone, limestone, granite, syenite, and indeed a vast heterogeneous assemblage of rocks. As for fossils, it is a perfect museum of them, and the late Mr. N. T. Wetherell made quite a large collection from the southern termination of this deposit on the heights of Muswell, Finchley, etc., on the north of London. *Gryphea incurva* from the Lias, and *G. dilatata* from the Oxford clay, are especially common. Watford, Rugby, and Charnwood Forest mark the westward extension of the Chalky Boulder Clay, and it ranges thence northwards into Lincolnshire, and eastwards to the North Sea, thus occurring more or less all over the eastern counties. In some places it attains a great thickness. At Boston, a well-sinking in 1828 passed through 24 feet of fen beds (peat and silt), then through 460 feet of boulder clay, and lastly penetrated 88 feet into the Middle Glacial Sands. Elsewhere it varies from a few feet to above 100 feet in thickness. The stones which it contains are usually angular or sub-angular, and are frequently grooved, scratched, or striated, especially the limestone and chalk masses. It contains no shells or remains of life of any kind which lived during the time of its formation.

It seems probable that the Scotch *Lower Till*, also an unfossiliferous stony clay, and the *Lowest Boulder Clays* of Lancashire and of Ireland, are of about the same age as the Great Chalky Boulder Clay of the east of England. Much of the gravel, too, of the west and south of England may be of this date.

Dimlington Inter-Glacial Beds.—At Dimlington

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near Spurn Head, in the south-east of Yorkshire, and at Bridlington, just south of Flamborough Head, we get thin stratified deposits, containing *Nucula Cobboldiæ* and other shells. Much of the gravel (with erratic blocks) of the central counties of England, which is commonly called 'Northern Drift,' may belong to this period.

The Purple Boulder Clay.—This is seen to overlie the fossiliferous seams at Dimlington and Bridlington. It is unstratified, tough, and of a purplish-brown colour, containing angular and striated stones. In the lower part it is very

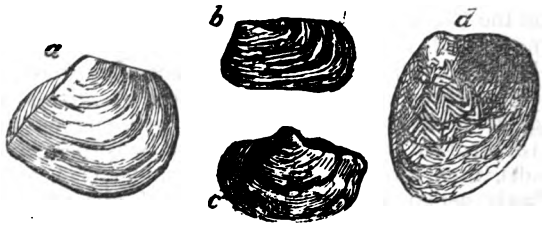

Fig. 35. (*a*) Tellina balthica. (*b*) Saxicava rugosa. (*c*) Leda truncata. (*d*) Nucula Cobboldiæ.

chalky, but this material gradually diminishes in amount upwards. The purple clay is exposed along the Yorkshire coast between Bridlington, Flamborough Head, and Speeton. It may be correlated with the *Lower Boulder Clay* of Lancashire and Cheshire. The latter has yielded numerous shells of arctic species to the researches of local geologists.

Upper Inter-Glacial Sands.—In Lancashire and Cheshire, and in Wales, we find sands and gravels, which attain on Moel Tryfan a height of 1300

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feet, and near Macclesfield of 1200 feet. These beds have been carefully searched by Messrs. Trimmer, Darbishire, Shone, De Rance, Shrubsole, and others, and have yielded a fauna which is remarkable for the mixture of northern and southern shells, containing such warm-water species as *Venus chione* and *Arca lactea* side by side with Scandinavian forms like *Natica affinis*, etc. It is, however, now considered that the latter shells were washed out of older beds, and that in these Upper Sands we have evidence of a mild period. The shells are mostly found in seams of fine shingle, and many minute specimens have been got by washing carefully the contents of the larger shells, also the stuff contained in holes in stones. During the period of this great depression in the west of England, the eastern counties do not seem to have subsided more than 40 feet, so that hardly any deposits of this age are found there.

The Hessle Sands and Gravels, however, are probably of the same age as the Middle Sands of Lancashire and Cheshire. Hessle is the name of a village on the Humber a little west of Hull. Here the gravels are exposed in the cliff, and also near Burstwick, Kelsea Hill, Paul Cliff, etc. Besides marine shells, they are remarkable for containing *Cyrena fluminalis*, which is now only known to live in the Nile and in the rivers of Thibet and China. The gravels at Barnwell near Cambridge, and the gravels and brick earths of the Thames valley are probably of this age. They contain *Cyrena fluminalis*, and also rude stone implements. They also contain remains of the mammoth (*Elephas primigenius*), great Irish elk (*Megaceros Hibernicus*), cave lion, cave bear, hyæna, rhinoceros, hippopotamus, etc.

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Above the sands comes the *Hessle Boulder Clay*, which may be of the same age as the Upper Boulder Clay of Lancashire and Cheshire. It is exposed along the coast of Holderness, and runs down the east of Lincolnshire between the chalk wolds and the sea, as far as Firsby on the edge of the Fen district.

Kames and Eskers.—These are names applied to long banks, or ridges, or hummocks of gravel and sand, which occur commonly in Scotland and Ireland, and of which there are a few in the north of England.

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CHAPTER XIX.

HOW THE GLACIAL DEPOSITS WERE FORMED.

MANY theories have been advanced to account for the formation of the surface deposits which we have been considering. As to the (inter-glacial) beds of sand and gravel, there is no difficulty; these were certainly deposited in moderately shallow seas, the currents of which appear to have been very variable. As to the Boulder Clays, it is generally considered that they are due to the action of *ice;* but there is still much controversy as to whether they were formed underneath a glacier moving over a land surface, or whether they were dropped from icebergs. The hard rocks of Scotland, of Ireland, and of the north of England, bear indubitable marks of having been traversed—rubbed over, as it were—by an ice sheet. This is plain from the groovings or *striations* still found on the rock surfaces at many points. These were done by stones held fast in the slowly-moving glacier, which ground them like so many chisels into the rock beneath. The *polished* rock surfaces, too, the rounded aspect of the hills, and the smoothed hummocks (*roches moutonnées*, as they are called), all tell the same tale. Then, by the stones found embedded in the Boulder Clays, we can tell the direction in

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which the ice sheet travelled; for many rocks, such as the famous granite of Shap Fell, are very distinct from all others in the country, and can be easily identified. The angular character of these embedded stones tells us that they were not transported by liquid water, for that would have rounded them; they must have been conveyed by *ice*, and the scratches they bear were inflicted in the process of carrying. It is very striking in many places to see huge stones of many tons weight perched on a hill-top, which have evidently travelled from a distance, for they are often of

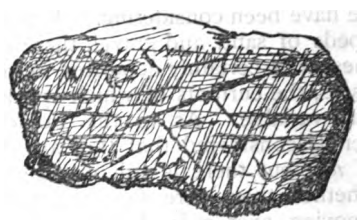

Fig. 36. Scratched chalk pebble, from the Great Chalky Boulder Clay, Leicester.

granite, while the rock upon which they rest may be slate, etc. These are known as 'erratics,' or *blocs perchés*. To the untaught they are objects of wonder, and local traditions usually refer them to some action of the Evil One; but the educated eye sees in them clear evidence of a time when the climate of this country was intensely cold, when immense ice sheets or huge glaciers covered not only our islands, but a great part of the northern hemisphere, down as far as 50° north latitude in Europe, and to 39° in North America.

This period was apparently not one of uninter-

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rupted cold. The beds of sand and gravel, with shells and bones and implements of man, which occur *between* the beds of Boulder Clay, tell us of mild inter-glacial times, when the ice retreated and the land was habitable. The maximum of cold was apparently reached at the time of the formation of the Great Chalky Boulder Clay. According to Mr. James Geikie, this was formed underneath a great glacier, which, descending from the north, rubbed up and carried on portions of all the rocks over which it passed, and reached as far south at least as the north side of the valley of the Thames. But Mr. Searles V. Wood, jun., would assign the same deposit to icebergs which broke off from a glacier, ending say between Lincoln and Horncastle. As these bergs drifted southwards, they melted or broke up, and dropped their freight of stones and mud on the sea bottom. Sometimes they grounded, and then we get great contortions of the underlying beds. One fact which favours the iceberg theory is that this boulder clay frequently rests in the eastern counties upon the inter-glacial sands in a perfectly regular and even manner, while it is urged that a glacier passing over such a deposit would cut it out, or, at all events, greatly disturb it.

Cause of the Cold of the Glacial Epoch.—Many theories have been advanced of late years to account for the variations in climate which the earth's surface has evidently undergone in past ages. Some of these theories may be briefly enumerated. (1) Sir Charles Lyell supposed that an alteration in the relative amount and distribution of land and sea would produce the required effect. He considered that if the land formed a broad belt round the equator, while the sea occu-

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pied the polar areas, that the latter would then be warmed by hot winds blowing from the equatorial land, and any islands in these polar seas would enjoy a temperate climate. With an opposite arrangement of land and sea, he thought a Glacial Epoch would be the result. *But* there is no evidence of such frequent and vast changes of elevation as this theory would require during our last Glacial Epoch; and, moreover, the air warmed by the equatorial land would certainly there ascend, and radiate most of its heat into space, without conveying it to the poles. (2) Mr. John Evans

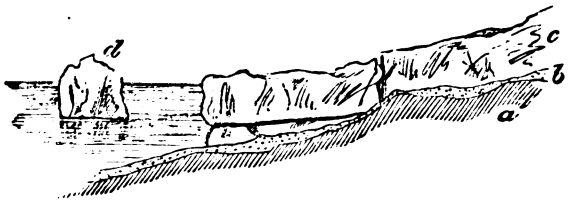

Fig. 37. Glacier entering the sea and shedding an iceberg. (*a*) Rock over which glacier is moving. (*b*) Ground moraine. (*c*) Glacier. (*d*) Iceberg.

has advocated the theory of the *shifting of the poles*. If in the Glacial Period the North Pole was in or near the British Isles, we can readily understand the fact of their glaciation. This theory has much to recommend it; but the great obstacle is the bulge of the land round the equator, which imparts great stability to the present axis of rotation; and the theory would require immense elevations of other parts of the earth's surface to counterbalance this, and the opinions of mathematicians are against it. (3) Mr. Belt and Lieut.-Col. Drayson think that an increase in the obliquity of the ecliptic would give

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increased cold; but their views have met with no acceptance either from astronomers or geologists. Then we have numerous somewhat fanciful ideas, as (4) that the sun has given out varying amounts of heat in past ages, sometimes more, when even the polar regions were warm, sometimes less, when great ice-caps were formed. (5) That the solar system in travelling through space has sometimes to pass through colder, and at others through warmer regions. (6) Lastly, the theory which has of late met with most acceptance is that advocated by Dr. Croll in an able work, entitled *Climate and Time*. He points out that it is a well-known astronomical fact that the earth's orbit changes in form. When it is most elliptical, the earth is, when nearest to the sun, 84¼ millions, and when farthest off, 98½ millions of miles distant from it. At present, the earth's orbit is very nearly circular; but 200,000 years ago it was more elliptical, and then commenced the series of glacial and inter-glacial periods, which terminated, Dr. Croll thinks, 80,000 years ago. The glacial periods happened in the northern hemisphere when the North Pole was turned away from the sun at aphelion (*i.e.* when the earth was farthest from the sun), the southern hemisphere at the same time enjoying a perennial spring—an inter-glacial period, in fact. But when, owing to the precession of the equinoxes, the earth's North Pole was turned towards the sun at perihelion (*i.e.* when the earth was nearest to the sun), then the opposite state of things happened, and the southern hemisphere was glaciated. So for more than 100,000 years did glacial and inter-glacial periods alternate in each hemisphere at intervals of about 12,000 years, and of such variations we have already pointed out the evi-

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dence afforded by the Drift deposits of the British Islands.

It is most important to notice, however, that the cold was an *indirect* effect of the eccentricity of the earth's orbit. The hemisphere whose winter occurred in aphelion would receive one-fifth less heat in winter, and one-fifth more heat in summer, than at present, and the winter would be thirty-six days longer than the summer. Hence, the winter being both colder and longer than at present, there would be an increased fall of snow and production of ice. At present the south-east trade winds are stronger than the north-east, and they deflect the equatorial current to the north of the equator, sending the Gulf Stream to warm the northern seas. But when the northern hemisphere was the colder, the north-east trades would be the stronger (for their force depends on the *difference* of the temperature between pole and equator), and they would deflect the Gulf Stream into the Southern Atlantic. This deflection of heat-carrying currents Dr. Croll considers to be the chief cause of the great changes of climate during the glacial period.

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CHAPTER XX.

THE RECENT PERIOD.

UNDER this head we shall include all the deposits which have been formed since the cold of the last Glacial Epoch passed away. These beds may also be termed *Post-glacial*, although this name has been applied (incorrectly, as we think) only to the beds, such as the Hessle Boulder Clay, etc., which immediately succeed the Chalky Boulder Clay, and which themselves are clearly of glacial origin.

Considering these *recent* strata broadly, we see that the fossils which they contain are all identical with living species. Of course, there are a few exceptions to prove the rule. Thus the great Irish elk, whose bones we find in the peat bogs of Ireland, may have lived there until days not long before the commencement of the Christian era. Even in our own times the disappearance of species is not unknown. No living specimen of the great auk (*Alca impennis*) has been seen for more than forty years, while it is two centuries since the last dodo was slain.

Alluvial Deposits.—These are the beds of loam, gravel, sand, etc., which form the flat lands on either side of the course of our present rivers. They are the so-called 'river meadows' of the

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Trent, the Humber, the Thames, Severn, Ouse, etc. In times of flood the rivers still overflow these tracts of marsh or meadow land, each inundation adding a film of sediment to the surface. In considering the great breadth of many river valleys, we must not think that the stream ever occupied the entire width at once, but rather that it has continually shifted its course, swaying from side to side of the valley, and gradually deepening it. If in our country the rivers no longer do this, it is because they have been domesticated, have been confined by man to fixed courses by means of

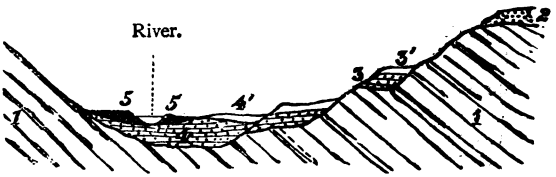

Fig. 38. Section across a river valley. 1. Old rocks. 2. Glacial gravel. 3. High-level river gravel covered by 3′ loam of the same period. 4 and 4′. Gravel and loam of present river. 5. Peat.

embankments, and are no longer permitted to wander at their own will. In these beds of alluvium we shall find shells, such as still live in the adjoining river, *Unio*, *Cyclas*, *Pisidium*, etc., with bones of such mammals as the deer and ox. Often the gravels occur at considerable heights above the present stream-courses, when they show us how the river has deepened its valley since the time of their deposition. The 'high-level' gravels of the Thames and of the south of England may be of Mid-glacial age, but in the north such deposits would be almost invariably cleared out by the

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recurring glaciers, and the valleys filled up with boulder clay, which the streams have since then partially denuded, again clearing out the valleys.

Silt is a deposit of impalpable mud cast up by the sea. The extensive tracts known as the Fenland, Romney Marsh, Pevensey Level, the Somersetshire Levels, and the Fylde of Lancashire are composed largely of silt.

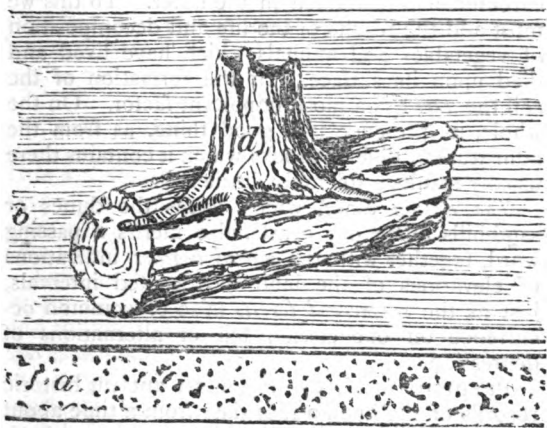

Fig. 39. Buried Forests in the Fenland. (*a*) Gravel. (*b*) Peat. (*c*) Trunk of fir tree. (*d*) A fir growing astride the trunk (after Skertchley).

Peat often occurs interstratified with the silt. It consists of the matted remains of mosses of the genera *Sphagnum* or *Hypnum*. During its formation the climate was probably much moister than at present, and the rainfall far greater. In the Fenland there are at least three distinct beds of peat. These contain the remains of great forests;

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and the manner in which some trees are seen to have grown on the top of the stumps or prostrate trunks of a previous generation is often extremely curious.

The Soil of our fields is, too, a recent formation. It consists of the material of the rocks below disintegrated by frost, by the mechanical impact of the falling rain, and by the chemical action of the carbonic acid contained in the latter. To this we must add the results of the life and decomposition of vegetables and animals which have lived and died upon its surface. In the formation of the soil the *Drift* is a most important factor. On the whole, its presence is a good thing, as from the admixture of different rocks which it contains there usually results a tolerably fertile soil.

The Blown Sand, which forms the dunes or sand-hills along our coasts, also merits a passing word, together with the *raised beaches*, indications of elevations of the land at repeated intervals, just as the *submerged forests* (also of common occurrence on our coasts) tell of alternations of depression.

PREHISTORIC MAN.—The most ancient historic records of the human race date from a time about 2000 or 3000 years before the Christian era. Such evidence as we possess relating to the existence and habits of man at this time, show that the people dwelling in Western Asia were then acquainted with the manufacture of *iron*, although they still used *bronze* for many purposes. Homer's heroes, too, used weapons chiefly of bronze, but some were of iron. Bronze is an alloy of copper and tin, containing about nine parts of the former to one of the latter. There was, however, a time when iron was unknown to any nation, and bronze

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only was used. Hesiod, writing B.C. 850, refers to this time, and it is clear that the use of bronze everywhere preceded that of iron. In North America, again, this Bronze Age seems to have been preceded by a Copper Age, as implements fashioned out of that metal only have been found there; a few have also occurred in Europe. But earlier still, when the use of metals was altogether unknown, man made all his implements of *stone*, selecting flint almost universally for the purpose. Thus we have—

1. The Stone Age.
2. The Bronze Age.
3. The Iron Age.

It is with the Stone Age that we are chiefly concerned, and it is entirely owing to the labours of geologists that of late years so many new facts about prehistoric man have been found out.

First of all we must be certain that these rude stones do really bear traces of man's handiwork, and to this end it will be necessary to make ourselves acquainted with the properties of flint, and the manner of working it. For this purpose we must provide ourselves with some good-sized nodules or lumps of flint, and a light hammer. Holding the flint in the left hand, we steady the wrist upon the knee, and then proceed to strike several sharp blows along the edge. Each of these blows should detach a flake of flint. Having become pretty expert, a round heavy pebble may be used instead of a hammer with similar results. On examining the flakes we have struck off, each will be found to exhibit a protuberance or swelling, or *bulb of percussion*, at the point where the blow was struck, corresponding depressions, of course, exist-

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ing on the parent block or *core* from which they were detached.

Now when we find flints, which bear marks of having been fashioned in this way, in undisturbed beds of gravel, sand, brick earth, etc., we assign to them a similar artificial origin, and as man is the only tool-making and tool-using animal, we regard these flint implements as proofs of his existence before or during the formation of the said deposits.

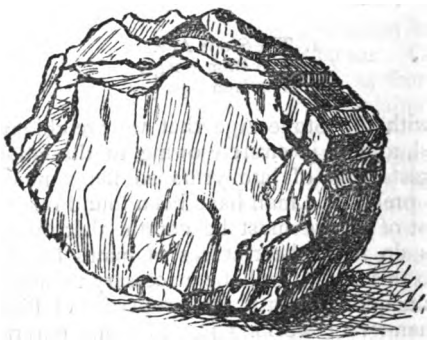

Fig. 40. Flint core with the flakes which have been struck off replaced upon it.

The first person who seems to have specially noted these artificially-fashioned stones in gravel beds was the late M. Boucher de Perthes, who found many about 1847 in gravel pits near Abbeville and at St. Acheul, near Amiens, in the valley of the river Somme, in the north of France. His discoveries were confirmed in 1859 by Messrs. Falconer, Prestwich, and Evans, and similar discoveries were soon made in England by Mr. Wyatt

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at Bedford, and by numerous other observers at various points in Norfolk and Suffolk, and in the valley of the Thames. All the implements were made of flint; they were of an oval or pointed form, usually from three to seven inches in length; their surface was glossy, generally stained and discoloured, often covered with dendritic markings, and the angles more or less worn and rounded. In the same beds, bones of the mammoth, rhino-

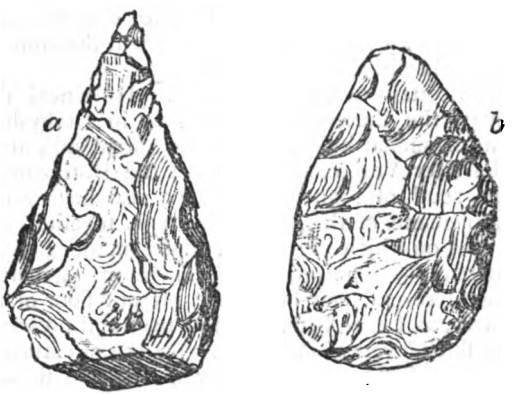

Fig. 41. Palæolithic flint implements. (*a*) Pointed type. (*b*) Ovate type.

ceros, reindeer, etc. have been found, some of which are now extinct, while others cannot now inhabit this country, owing to the change of climate which has since taken place.

No other traces of man, no pottery, no human bones, have yet been found in the gravels which yield these rude stone tools. The deposits are evidently of great age. Some, as we have seen,

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clearly underlie successive sheets of boulder-clay in Norfolk. Others, as near Bournemouth in Hampshire, are found on the tops of cliffs, high above the level of any neighbouring river. In fact, these high-level gravels in Hampshire and the Isle of Wight are believed to have been deposited by a river which in old times ran where the Solent now is, and helped to sever the Isle of Wight from the mainland. For these river gravel implements Sir John Lubbock has proposed the name of *Palæolithic* (*palaios*, ancient, and *lithos*, a stone), and the time when they were made would therefore be the Palæolithic or Older Stone Age.

In certain caverns, as at Kent's Hole near Torquay, the Cresswell Crags Caves in Derbyshire, and in similar hollows in the limestone cliffs along the river Vezère, a tributary of the Dordogne, in the south of France, there have also been found implements of this *palæolithic* type, together with bones on which are carved representations of the mammoth, reindeer, etc. These are generally found several feet below the present floor of the caves, and have been covered over and preserved by thick layers of *stalagmite*, a deposit of carbonate of lime left by the waters which trickle through such caves. Icicle-like masses which hang from the roof have a similar composition and form, and are known as *stalactites*.

The Neolithic Stone Age.—No matter in what part of England we may dwell, if we know what to look for, and keep our eyes open in the course of our geological walks, we may fairly expect to find flint implements of the later or *Neolithic* (*neos*, new, and *lithos*, a stone) type. They occur usually in the surface soil, just underneath the grass, so that when the ground is bared for any purpose,

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we should keep a sharp look-out. The rounded mounds known as *barrows* or *tumuli*, which are the burial-places of the chiefs or mighty warriors of the prehistoric nations, will usually yield some on excavation. On the chalk hills, where flint is plentiful, there seem to have been regular manufactories of these flint tools set up; as, for example,

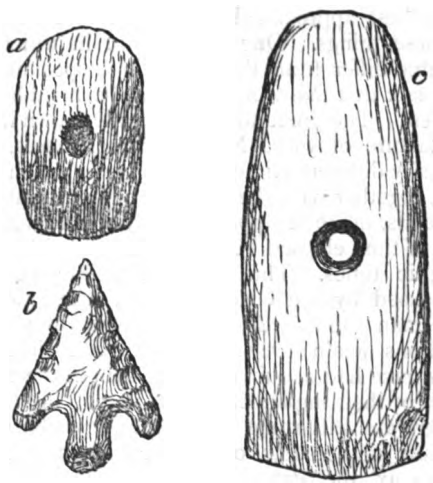

Fig. 42. Neolithic flint implements. (*a*) Hammer-stone. (*b*) Arrow-head. (*c*) Perforated celt.

on Cissbury Hill near Worthing, Grimes' Graves near Norwich, and at many places on the Yorkshire Wolds. Of these tools some are merely *flakes*, with a sharp cutting edge, used perhaps as knives; others have a rounded edge, and are called *scrapers*, because we think their purpose was to remove the

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fat, etc., from the inside of skins when they were being dressed or prepared for clothes. There are many arrow-heads, some plain, some barbed, with sling-stones, picks, chisels, and gouges. Large specimens, like axe-heads, are called *celts;* some of these are perforated for the insertion of a handle. Many of these tools and weapons exhibit the highest skill in their manufacture—a skill which will be best appreciated by those who try to imitate these things. One great point in which the Neolithic differ from the Palæolithic specimens is in the fact that many of them have been rubbed or polished. The great advance in skill shown in the manufacture of these Neolithic implements, and the totally different circumstances under which they occur, together with the absence of any transition specimens, make it appear plainly that a great interval of time elapsed between the Palæolithic and Neolithic times. This gap Mr. Geikie believes was caused by the Glacial Period, when the ice drove man southwards, not to return till warmer conditions again prevailed, by which time the human race had acquired greater skill in the manufacture of their implements.

There are still some savage nations who make and use implements of stone. Such are the Esquimaux, the Patagonians, etc. It is by the study of the way in which these modern savages make and use their stone tools that of late years we have been able to find out so much about these ancient stone implements made and used in our islands thousands of years ago.

Then came the discovery of metals, their properties perhaps first revealed by an accident, for the earliest copper tools appear to have been hammered into shape as if they had been thought

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merely 'malleable stones.' The Bronze Age appears to have been of comparatively short duration, for the superior qualities of iron caused it soon after its discovery to supersede bronze. But now we enter on historic times, and the geologist gives place to the archæologist and the historian.

THE END.

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